# UNIVERSITY OF NAIROBI

## SCHOOL OF ENGINEERING

## INTEGRATING SOLAR ENERGY IN HOT WATER GENERATION BY A STEAM BOILER: A CASE STUDY OF A HOSPITAL

By

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A REPORT SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY MANAGEMENT OF THE UNIVERSITY OF NAIROBI.

## DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

## NOVEMBER, 2021

## Declaration

I **Lawrence Muma Mangerere**, hereby declare that this report is my original work. This work has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. The copyright of this report belongs to the Author and due acknowledgement must always be made of the use of any material contained in or derived from this report.

Signature: Date...23rd November, 2021

## Supervisors' Declaration

We confirm that the study was carried out under our supervision and has been submitted for examination with our approval as University supervisors.

**Dr. R. Kimilu** ..............................

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**Dr. A. Aganda** ..............................

Signature...............................Date.............................

## Acknowledgement

I am deeply indebted to the following for the guidance, support and encouragement they provided during the course of the research project. First, my project Supervisors Dr. Richard Kimilu and Dr. Alex Aganda.

I am grateful to the Mechanical Engineering department staff at the University of Nairobi for the support in the project.

I am profoundly thankful to my family members for the moral support during the research.

## Dedication

I dedicate this report to my family for their understanding and moral support during the research and report writing.

## Abstract

In many countries, efforts are being made to limit the use of fossil fuels as a source of energy. The use of fossil fuels for many years has led to increased emissions of gases responsible for climate change. In a number of cases, the reduction in use of fossil fuels is being compensated for by using renewable energy; especially solar and wind power. Among high fossil fuels users are hospitals that use fuel fired boiler systems to produce hot water and steam, which are vital utilities in hospitals. Among alternatives to thermal energy source for hospitals is solar thermal heating. Though solar is a clean source of energy, its variability and dependency on weather makes it impossible to fully replace fossil fuels. However, if well integrated to existing systems, can significantly reduce the fuel use.

The objective of this study was to evaluate the viability of integrating a solar thermal system to an existing fuel fired hot water/steam boiler system in a hospital (H1). Three hospitals were involved, all located in Nairobi. Two of the hospitals use fuel oil while the third use electricity to generate hot water. The hospitals, H1, H2 and H3 have bed capacities of 225, 176, and 103, respectively. Hospitals H1 and H2 have a fuel fired boiler systems, while H3 has an electrically heated boiler system. Energy costs for thermal water heating for hospital H1 and H3 were US$ 0.88 and 2.14 per inpatient bed day, respectively. There were no records for thermal water heating for hospital H2. A thermal solar heating system contributing a 40% heating component for was designed for integration to Hospital H1. The initial investment cost was US$ 60,197. Economic analysis showed that the annual energy cost saving would be US$ 23,766. This would lead to a simple payback period of 2.53 years and a return on investment (ROI) of 39.5%. At a discount rate of 15%, the net present value of the integrated system would be US$ 59,083 with an internal rate of return (IRR) of 40%.

The study established that electrical water heating was more costly per inpatient bed day compared to thermal heating. Integration of solar heating to thermal heating at a 40% contribution would save 945 GJ per annum equivalent to 75.5 tons of $CO_2$. The analysis indicated that incorporating a solar heating system to the existing heating system for H1 is economically feasible. A comparative study on energy saving on a working solar integrated water heating system is recommended.

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## Nomenclature

| | |
|---|---|
| ASHRAE | American society of heating, refrigerating and air conditioning Engineers |
| ASME | American society of Mechanical Engineers |
| CIP | Cleaning in place |
| CPCs | Compound parabolic collectors |
| DHW | Domestic hot water |
| EPRA | Energy and Petroleum Regulatory Authority, Kenya |
| ETCs | Evacuated tube collectors |
| FPCs | Flat plate collectors |
| GSES | Global Sustainable Energy Solutions |
| IbD | Inpatient bed day |
| IRR | Internal rate of return |
| NASA | National Aeronautics and Space Administration |
| NPV | Net present value |
| OECD | Organization for economic cooperation and development |
| PTC | Power test code |
| ROI | Return on investment |
| SPBP | Simple payback period |
| WHO | World Health Organization |
| ppm | Parts per million |

# Chapter 1: Introduction

## 1.1 Background

All hospitals require domestic hot water normally at 50°C to 60°C as an essential utility service. Domestic hot water comprises of all the water used for sanitation, personal hygiene and food preparation in a building. Water temperatures under natural conditions in Nairobi range from approximately 15°C to 25°C as per the profile in Appendix A6-1 and hence heat energy needs to be added to the water to raise its temperature to the required level. Domestic hot water in a typical hospital is used in washrooms in the wards, the kitchen and laundry. The amount of domestic hot water used in most hospitals is substantial and hence requires substantial amount of energy for its generation.

In hospitals, domestic hot water can be produced in a variety of ways utilizing various energy sources including: natural gas or oil in conventional boilers and electricity. Additionally, water can be heated directly by the sun through the use of solar thermal technology which includes solar collectors, storage tanks and heat transfer media. In some cases, a hybrid of these technologies is used for domestic water heating (McNulty, 2013)

The boilers may directly raise the water temperature or they may generate steam which then transfers energy to the water using heat exchangers. The use of fossil fuels in boilers to generate hot water results in emission of carbon dioxide, sulphur dioxide, sulphur trioxide and nitrous oxides which lead to environmental pollution and global warming (Woodruff Everett B., 2004).

At the moment, global warming has reached a critical stage and every effort is being made to reduce use of fossil fuels. One such effort is to increase the use of renewable energy sources notably wind and solar thermal. Although wind and solar energy sources can generate hot water on their own, their variability makes it difficult to have consistent supply of energy and at a constant rate. One way of addressing the variability is to integrate the renewable sources of energy into the oil or/and electricity-based systems. The oil and electricity systems will be called upon whenever the wind and or solar energy is not available.

Overall, it is anticipated that the integrated system will produce hot water cheaply and reduce pollutant emissions to the atmosphere.

Generating hot water by fossil fuels has been found to be more expensive than by solar thermal technology ( Denholm P., March 2007). After installation, solar thermal is considered free energy.

Generally, a steam boiler using automotive gas (diesel) oil will produce approximately 14kg of steam at 7bar (g) from 1 litre of oil at ksh.100 (1 US$).

The high cost of fuel used in generating hot water makes the provision of healthcare more expensive to all. This study examines hot water generation in three hospitals. The first hospital H1 has the highest bed occupancy at approximately 67,268 inpatient bed-days per year and uses oil fired boilers to generate the required domestic water. The second hospital H2 has a bed occupancy of approximately 47,282 inpatient bed-days per year. The third hospital H3 has the smallest bed occupancy at 29,180 inpatient bed-days per year and uses electricity to generate hot water.

A bed-day is a day during which a person is confined to a bed and in which the patient stays overnight in a hospital as defined in the OECD health data extract in Appendix A7

All solar water heating systems use the same basic method for capturing and transferring solar energy using low, medium or high temperature collectors. Different types of collectors, materials and systems are used depending on the expected operating temperature range.

Low temperature collectors are used primarily for domestic water heating to generate temperature levels of around 65°C. An effective solar water heating system should have adequate number of collectors at a suitable location, with correct orientation and inclination (tilt angle).

Medium temperature solar collectors use concentrators to achieve temperature levels of 100°C to 300°C. High temperature solar collectors use special concentrators to achieve a temperature level of more than 500°C to generate steam for electrical power production.

Solar energy can be used at various points of the existing water heating system including pre-heating make-up water to the boiler; feedwater to the boiler or heating water for the showers through a calorifier.

Hot water production and storage temperatures are required to comply with the health and safety requirements for the minimisation of legionella bacteria. This demands a minimum storage temperature of 60 °C and a minimum of 50 °C throughout the distribution system (The institute of plumbing, 2002 Edition).

This study seeks to establish the demand and cost of hot water as per the currently installed systems and estimate the changes in emissions and cost when solar thermal technology is integrated. The study will also determine the capital cost of installing (integrating) the solar thermal system.

It is anticipated that after integration, the cost of hot water production will be low and the emissions will reduce thus contributing to the reduction of global warming and the mitigation of climate change.

## 1.2 Problem statement

For a long time, the fossil fuels have been a major source of energy for a majority of countries. However, combustion of these fuels results in emissions of carbon dioxide, sulphur dioxide, sulphur trioxide and nitrous oxides. These emissions have been found to be responsible for increased environmental pollution and global warming.

Many sectors are examining their energy utilization with the object of reducing the fossil fuel consumption. An example is in generating hot water in hospitals, a vital utility. Many hospitals still use petroleum oil in boilers to produce hot water. Since the temperature of the hot water is between 50°C and 60°C, the solar thermal source is most suited in replacing the boiler oil. Low temperature solar systems can easily attain this temperature. The use of solar water heating can result in energy savings and reduction of pollution to the environment and hence contribute to mitigation of climate change. However, solar energy is not constant but varies according to the weather, time of the day and the geographical location. Also, solar energy is not available at night although there is demand for heating at that time. Because of the variability, the solar energy is best used when integrated with the fuel oil boiler system. It is in the integration process that this study is engaged.

### 1.3 The Existing Hot water generation system at hospital H1

Dry saturated steam is used to generate hot water for showers, kitchen and laundry. The live steam from the boiler is taken through a heat exchanger (calorifier) where it rejects the enthalpy of evaporation to cold water and in the process the temperature of cold water is raised to the required level. The target temperature for showers is 60°C.

The existing installation schematic in which steam is used to generate hot water in a calorifier is shown in Figure 1-1. The system consists of a diesel fired boiler which generates steam. The steam from the boiler is delivered to calorifiers for water heating, to steam hot pots in the kitchen for cooking and to the laundry dryer. Cold water is fed into the calorifiers by gravity from high level tanks. The steam transfers its enthalpy of evaporation to the cold water which is then heated to the required temperature of 60°C through the calorifier which is basically a heat exchanger. Hot water is continuously circulated between the calorifiers and the end uses by a pump. The end uses for hot water include the showers and wash hand basins in the wards, the kitchen sinks and the Laundry washing machines. The amount of steam delivered to the calorifiers is adjusted by a hot water temperature controller. A temperature sensor on the hot water return pipe from the end uses controls the size of opening in the controller and when the temperature is achieved the controller shuts off the supply of steam.

After giving up the enthalpy of evaporation, the steam changes phase from vapour into liquid (condensate) at high temperature. The condensate is then discharged from the calorifier through a steam trap into the condensate return pipe that delivers the condensate to the feed water tank. The condensate in the feed water tank is often topped up with makeup water to cater for steam and condensate leaks.

The steam is admitted into the kitchen hot pots and the laundry dryer through gate valves and after discharge of enthalpy of evaporation, the resulting condensate is returned to the boiler feed water tank through steam traps and steel piping. The gate valves are closed whenever the hot pots and the laundry dryer are not in use.

This is the system that needs to be integrated with solar thermal energy in order to reduce cost of heating water and emissions to the environment.

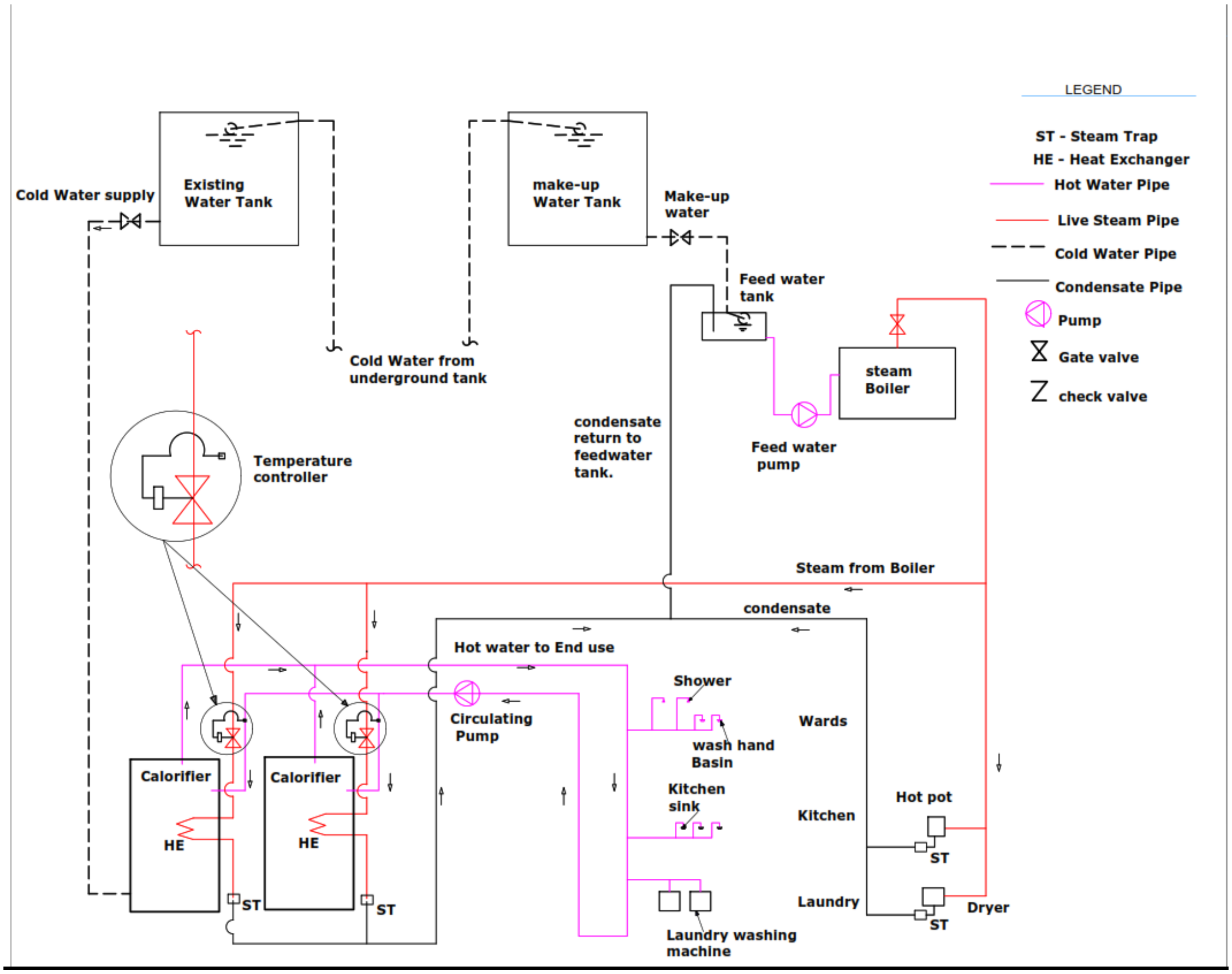



*Figure 1-1 Existing hot water system*

The World Health Organization (WHO) recommends that domestic hot water should be distributed at temperatures in excess of 50°C, with sufficient flow rates to prevent the growth of biofilms and bacterial cultures (McNulty, 2013).

## 1.4 Research Objectives

The overall objective of this study was to determine the cost benefit of producing hot water in an integrated solar and steam heating system and the resulting reduction of boiler emissions.

The specific objectives included:

1. Determination of the energy demand and cost of producing hot water in Hospital H1 and two other hospitals.
2. Determination of boiler efficiency at Hospital H1
3. Determination of size and quantity of solar panels required to meet the heating demand, establishing the corresponding reduction in $CO_2$ emissions and specification of components of the integrated steam and solar water heating system.
4. Economic evaluation of the integrated steam and solar water heating system

### 1.5 Significance:

The findings from the study will provide information on steam boilers and solar heating systems and highlight the importance of integrating the two. Integration of the two systems will lower the cost of water heating and reduce pollutant emissions to the environment. This will definitely contribute to reduction of global warming and mitigation of climate change.

# Chapter 2: Literature Review

## 2.1 Introduction

The purpose of this study was to estimate the energy demand for water heating in a hospital and the integration of solar thermal energy with the existing steam boiler heating system. In this chapter a review is made of production of hot water; performance of boilers; solar water heating and previous research relevant to this study.

## 2.2 Production of hot water

Domestic water comprises of all the water used for sanitation, personal hygiene and food preparation in a building. Domestic hot water can be produced from various energy sources including: natural gas or oil in conventional boilers, electricity and solar energy. In some cases a hybrid of these technologies is used for domestic water heating (McNulty, 2013).

The majority of the hospitals use fossil fuel fired boilers. The cost of producing hot water using fossil fuel fired boilers is high and the emissions from the boilers pollute the environment leading to global warming and climate change ( Denholm P., March 2007). Production of hot water using solar energy is cheaper but solar energy is not available throughout the day. Hence it is necessary to integrate solar thermal energy and fossil fuel boilers to generate hot water to meet the demand around the clock.

Dagim Kebede (Kebede, 2016) conducted a study entailing the design and analysis of a solar thermal system for hot water supply to Minilik II Hospital new building in Ethiopia. He used the Plumbing Engineering services design guide, 2002 Edition to estimate the heating demand of the hospital. He then used the heating demand to determine the number of solar collectors and the hot water storage capacity.

It was found that for Minilik hospital, for a total daily hot water demand of 30.475m$^3$, 108 collectors with a storage capacity of 18.3m$^3$ were required with an initial capital cost of 1,864,054 Birr (1 US$ =41.5 Ethiopian Birr) equivalent to US$ 44,917. The life cycle cost saving of the investment (solar water heating system) was 1,869,571 Birr (US$ 45,050). The simple payback period was 2.2 years.

Hot water production and storage temperatures are required to comply with the health and safety requirements for the minimisation of legionella bacteria. This demands a minimum storage temperature of 60 °C and a minimum of 50 °C throughout the distribution system (The institute of plumbing, 2002 Edition).

However, there are risks associated with storage of hot water in calorifiers, as the tanks can provide perfect breeding conditions for microbial growths such as Legionella. Legionella is a naturally occurring environmental pathogen common to aquatic environments. Inhalation of the bacteria can cause a particularly dangerous strain of pneumonia known as Legionnaire's disease. It can also cause a non-fatal condition known as Pontiac fever which can itself induce pneumonia.

### 2.3 Performance of Boilers:

Boilers should be maintained at good combustion efficiency in order to minimise the cost of service delivery and the pollution to the environment. Boiler efficiency is important in the production of steam and consequently the generation of hot water as the higher the efficiency the lower the fuel consumption for a given heating load. The basis of testing boilers is the American Society of Mechanical Engineers (ASME) power test code 4.1 (PTC-4.1-1964). This code defines and establishes two methods of determining efficiency: the input–output method and the heat loss method. Both methods result in what is commonly referred to as "gross" efficiency as opposed to "net" efficiency which would include the additional energy input of auxiliary equipment such as combustion air fans, fuel and feed water pumps. (Wayne C. Turner, 2007). The performance of boilers may also be rated using combustion efficiency. The combustion efficiency is determined using the heat loss method where only the heat losses due to the exhaust gases are considered. Combustion efficiency can be measured in the field by analysing the products of combustion in the exhaust gases. Typically, measuring either carbon dioxide ($CO_2$) or oxygen ($O_2$) in the exhaust gas can be used to determine the combustion efficiency as long

as there is excess air. Excess air is defined as air in excess of the amount required for stoichiometric conditions. In practice, it is not possible to get a perfect mixture of air and fuel to achieve complete combustion without some amount of excess air.

The percentage of oxygen in exhaust gas indicates the amount of excess air and this can be used to control the air to fuel ratio in the combustion process of a boiler (Wayne C. Turner, 2007). In combustion processes, there is an optimum level of excess air for each type of burner or furnace design and fuel type. Only enough air should be supplied to ensure complete combustion of the fuel, since more than this amount increases the heat rejected to the stack, resulting in greater fuel consumption for a given process output and low boiler efficiency (Wayne C. Turner, 2007). A summary of the optimum excess air levels for various fuels is provided in Appendix A-1.

Boiler combustion efficiency can be improved by optimizing the percentage of oxygen in flue gas through adjustment of the speed of the forced draft fan preferably by using a variable speed drive. The efficiency may also be improved by rodding the fire tubes to remove any accumulated soot and descaling of the water side of the tubes. Efficiency may also be improved by using an air preheater for combustion air and an economiser to preheat feed water.

Fossil fuels which include coal, natural gas, petroleum, shale oil and bitumen are the main sources of heat and electrical energy in the world.

The main sources of heat and electrical energy in the world include coal, petroleum, natural gas, shale oil and bitumen

All these fuels contain in addition to the major constituents (Carbon, hydrogen & oxygen), other materials including sulphur, metal and nitrogen compounds. The use of steam boilers results in emission of carbon dioxide, nitrous oxides, sulphur dioxide and sulphur trioxide which lead to environmental pollution and global warming (Woodruff Everett B., 2004)

## 2.4 Solar water heating

One of the most popular applications of solar systems is for domestic water heating. The systems are quite popular due to the fact that they are relatively simple and generally technically and financially viable. This category of solar systems belongs to the low temperature heat applications such as showers (Wayne C. Turner, 2007).

Solar energy is available in plenty in Nairobi as shown in figure 2-1 for horizontal global solar irradiation, Kenya and figure 2-2 for average monthly sunhours, Nairobi.

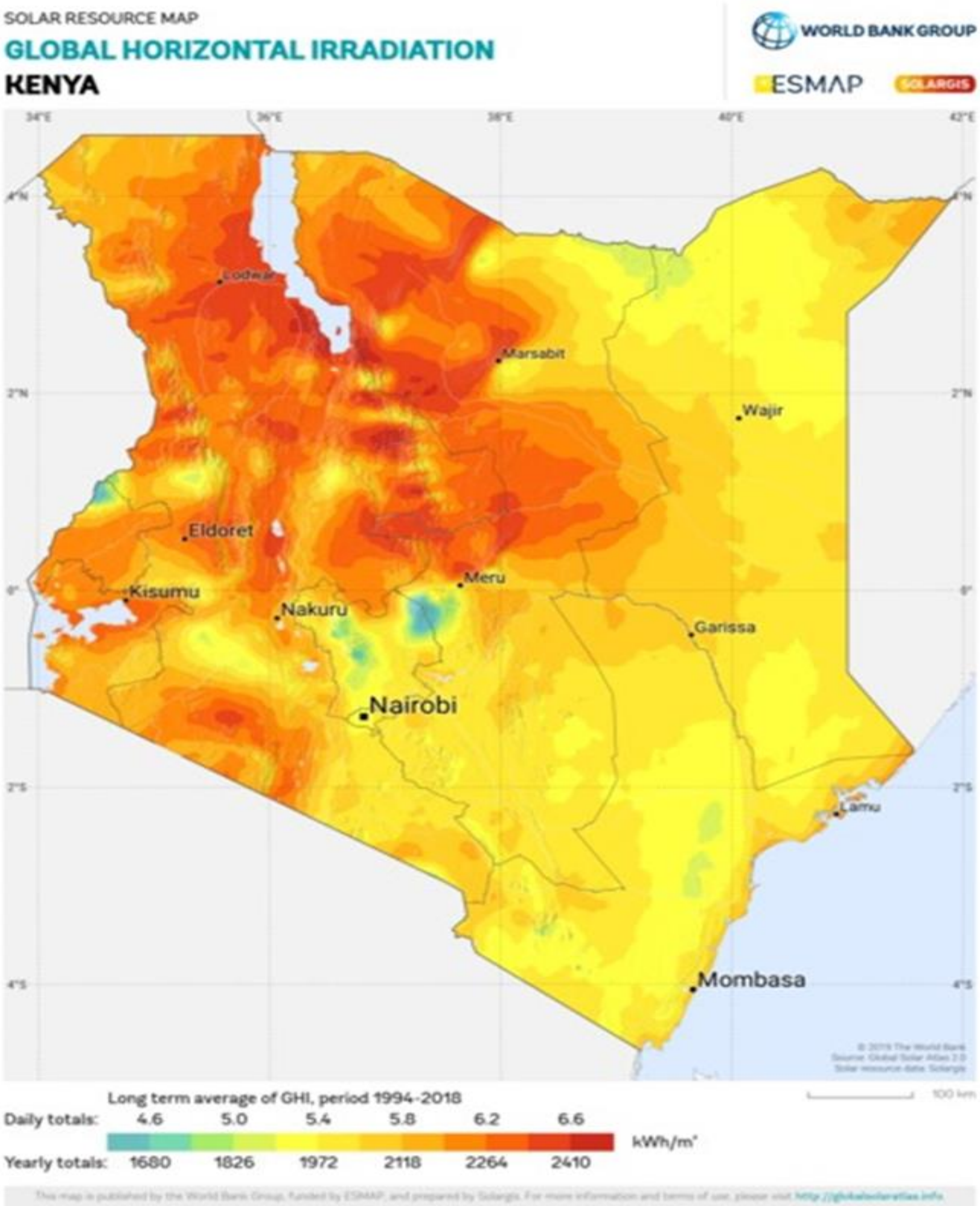



*Figure 2-1 Global solar irradiation, Kenya*

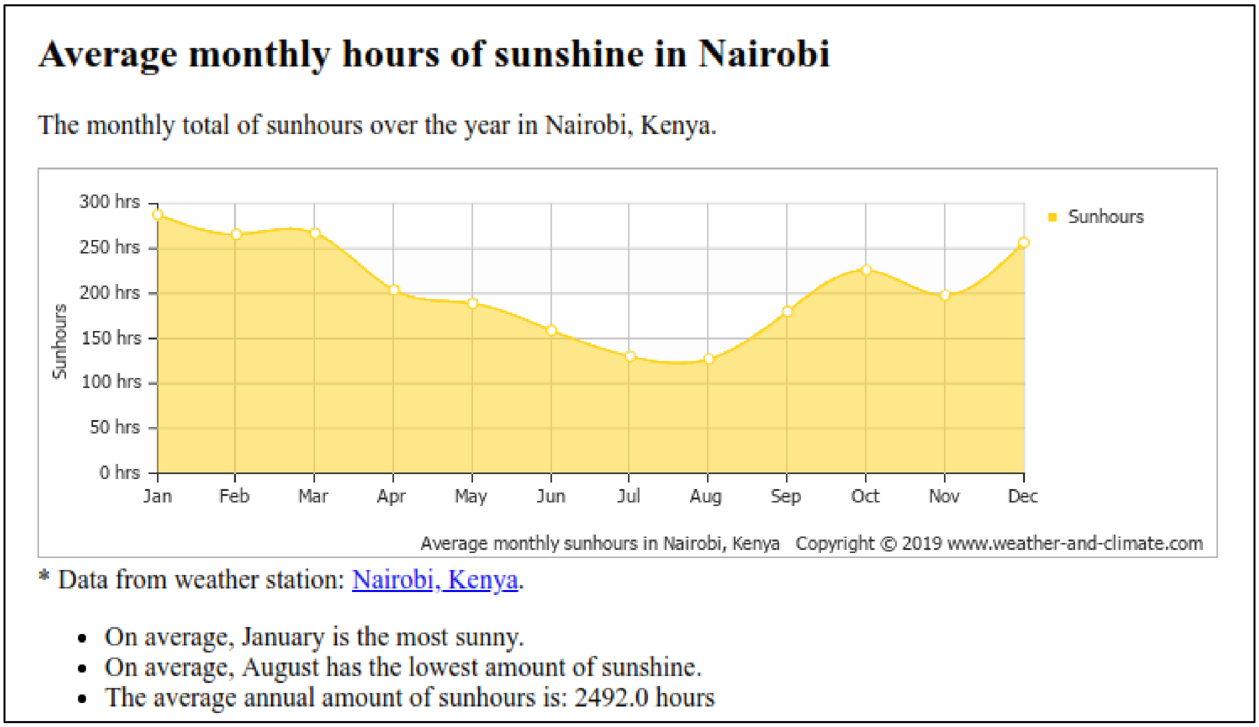



*Figure 2-2- Average monthly hours of sunshine in Nairobi.*

Additional irradiance data from the NASA website in respect of hospital H1, H2 and H3 is given in Appendix A6. A solar water heater consists of a solar collector, an energy transfer system including piping and a storage tank. The main part of a solar water heater is the solar collector, which absorbs solar radiation and converts it to heat. This heat is then absorbed by a heat transfer fluid which may include water, non-freezing liquid such as glycol or air that passes through the collector. The heat in the transfer fluid can then be stored or used directly. Two types of solar water heating systems are common including: Direct or open loop systems, in which water for various services is heated directly in the collector; and indirect or closed loop systems, in which the service water is heated indirectly by a heat transfer fluid such as glycol that is heated in the collector and passes through a heat exchanger to transfer its heat to the domestic or service water. Solar water heating systems are also different based on the method used to transport the heat transfer fluid and the systems include: natural circulation (or passive) systems; and forced circulation (or active) systems.

Natural circulation occurs by natural convection (thermo-siphoning), Forced circulation systems use pumps or fans to circulate the heat transfer fluid through the collector (Wayne C. Turner, 2007) . All solar water heating systems use the same basic method for capturing and transferring solar energy using low, medium or high temperature collectors. Different types of collectors, materials and systems are used depending on the expected operating temperature range.

Low temperature collectors are used primarily for domestic water heating. An effective solar water heating system should have adequate quantity of collectors at a suitable location, with correct orientation and inclination (tilt angle).

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and absorbing solar radiation, whereas a sun tracking concentrating solar collector usually has a concave reflecting surface to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. Concentrating collectors are suitable for high temperature applications. Solar collectors can also be distinguished by the type of heat transfer liquid used (water, non-freezing liquid, air or heat transfer oil) and whether they are covered or uncovered (Kalogirou, 2013)

Solar collectors can also be distinguished by their motion viz: stationary, single axis tracking, two axis tracking and operating temperature as shown in Appendix A.2. Stationary solar collectors are installed in fixed position and do not track the sun and they include flat plate collectors (FPCs) and evacuated tube collectors (ETCs) (Kalogirou, 2013). Some compound parabolic collectors (CPCs) are stationary with a concentration ratio of 1 whereas others have tracking and concentration capability of up to 5 (Kalogirou, 2013). The efficiencies of different types of solar collectors are given in appendix A3-1. Use of solar energy does not generate greenhouse gases and is friendly to the environment.

Greenhouse gases lead to global warming and climate change and they include carbon dioxide, chlorofluorocarbons, methane and nitrous oxides.

Solar water heaters may be classified as passive in which case hot water moves through the solar collector due to the thermosiphon effect or active in which case cold water is circulated through the collector to pick heat using a pump.

Passive systems have the collectors and tanks close to each other and the hot water storage tank is positioned higher than the collector to facilitate the thermosiphon effect. The thermosiphon effect is the circulation of water that occurs naturally through the collector due to convection. Hot water moves to the top whereas cold water moves to the bottom. A typical installation of a passive system is given in figure 2-3

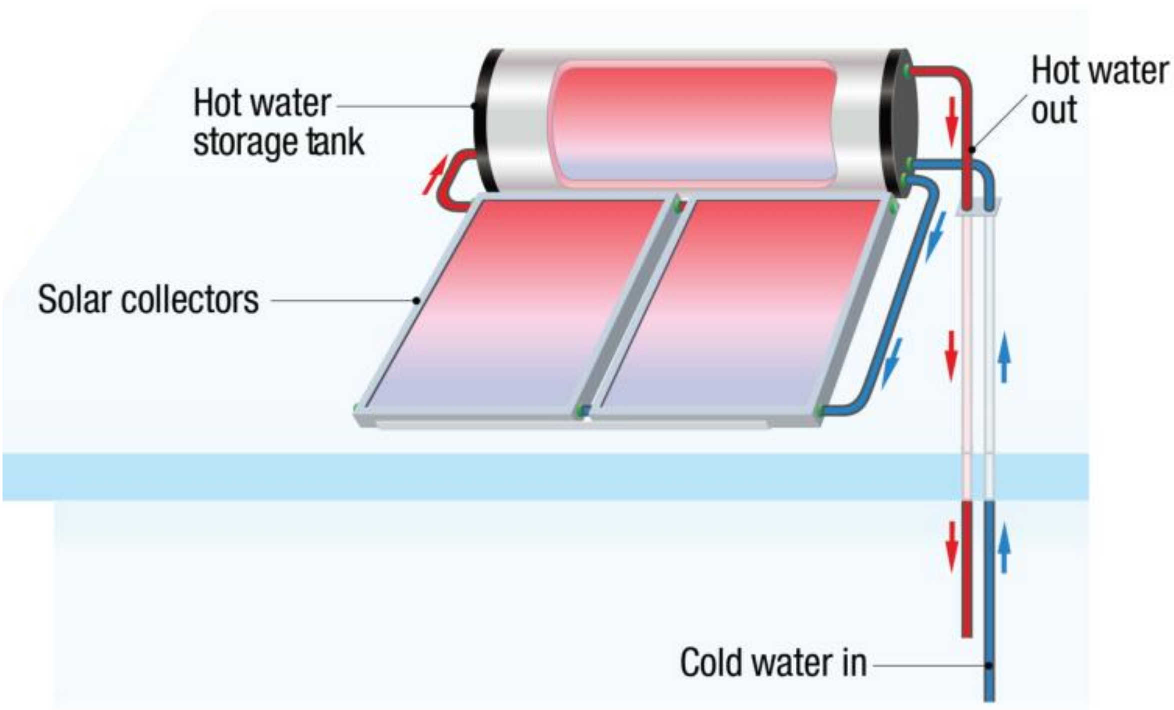



*Figure 2-3 shows a schematic of a typical passive solar water heater (courtesy of GSES).*

In an active solar water heating system, the solar collectors are located at a higher level than the hot water storage tank. In this case the thermosiphon effect does not work and a pump is used to circulate water around the collectors and the storage tank

Solar collectors may use a direct or indirect water heating systems. In a direct water heating system, water is circulated from the storage tank directly to the collectors where it absorbs solar radiation and is then delivered to the end users including showers. In an indirect water heating system, a working fluid such as glycol or glycol water mixture is circulated between the collector and a heat exchanger in the storage tank. The working fluid picks heat from the solar collectors and transfers it to the water in the storage tank. The temperature of the water in the tank rises to the required level after a continuous circulation of glycol or glycol water mixture for a period of time. A typical schematic of an indirect water heating system is given in Figure 2-4.

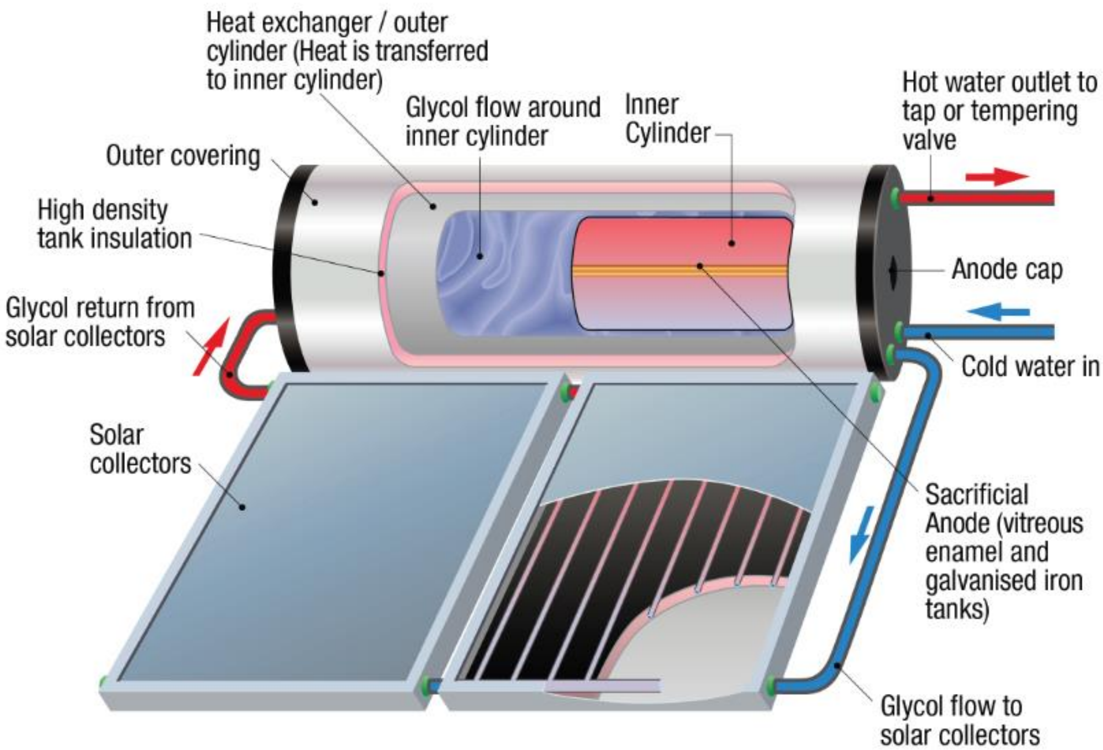



*Figure 2-4 shows a typical schematic of an indirect water heating system (courtesy of GSES)*

A Typical solar collector installation schematic with forced circulation is provided in Appendix A5. In this study, the objective was to integrate solar thermal energy with an existing steam boiler system. There are various points of integration including using solar energy to preheat make-up or feed water or to heat the water to the end users through a heat exchanger such as a calorifier.

**Hassan** (Hassan AL-Hasnawi, 2015) conducted three case studies in dairy and pharmaceutical plants in Sweden in order to determine the most promising integration points for parabolic trough solar collectors in terms of annual heat demand, temperature level and integration effort.

The study involved review of energy demand data, processes, instrumentation diagrams, boilers, feed water, steam network, hot water system and cleaning in Place (CIP) .

The integration concepts explored included:

1. Direct solar steam generation in which the concentrating solar collectors heated water part of which was converted to steam and fed directly to the steam drum /header whereas the liquid was pumped into the boiler as feed water.
2. Indirect steam generation in which case the hot water from the concentrating solar collectors was taken through a heat exchanger (reboiler) in the steam drum. The heat transfer media in the solar collector loop was either pressurised water or thermal oil.
3. Solar heating of boiler feed water and
4. Solar heating of make-up water

Two points were determined for solar integration in Pharmaceutical plant including the autoclaves and multiple effect distillers. Solar steam generation concepts were presented for both processes. The autoclaves were provided with steam at 4.5 bar intermittently whereas the multiple effect distillers were supplied with steam at 7 bar which was more or less constant.

Four points were determined for solar integration in dairy plants including: Low pressure steam line; heating of feed water for the boiler; clean in place (CIP) systems and pasteurizers.

Simulations were conducted for the low pressure steam line and heating of feed water confirming that a significant amount of excess heat is produced as a result of fluctuating heat demands and peak solar heat production hours. The study recommended that further investigation should be conducted in order to determine requirements of supplying the excess heat to other heat sinks (uses) (Hassan AL-Hasnawi, 2015). The results of the study show as follows:

-Saturated steam at 3 bar-g can be produced by heating boiler feed water from 120°C using solar heated pressurised hot water at 145°C indirectly in a kettle reboiler. It is possible to generate 650mwh from a collector area of 1375m² with a payback period of 10 to 11 years.

The findings from the research are relevant to this study. The mode of heat transfer at the kettle reboiler is similar to heat transfer at the hot water storage tank heat exchanger in the integrated system.

**Antonio Garcia** (Hortelano, 2011) conducted a study on water heating in an apartment building in Madrid, Spain. He estimated the building heating demand using Spanish "Real Decreto 1218/2002 table 4", legislation and used the estimate to size the solar water heating system which included number of solar collectors and storage tanks (accumulators). According to the Spanish legislation, 22 litres/ person / day of hot water at 60°C is required in an apartment building.

The solar collectors used were tilted from the horizontal and hence incident solar radiation on a horizontal plane had to be converted to an inclined plane in the design of the solar water heating system.

The research gave specifications of the solar water heating system elements including the solar panels, storage tanks, circulating pump and controls. The research determined the energy savings that would be realized by using solar energy and the corresponding reduction of $CO_2$ emissions.

The economic study covered the project cost, the simple payback period and the net present value (NPV). The projected investment cost on the proposed solar water heating system was 17962.1€ whereas the projected saving was 30023.9 kWh equivalent to 1640.8€ per annum. The simple payback was 11.9 years whereas the net present value (NPV) was 59.1€. The procedure for economic evaluation is useful in this study

**Daniel Sanchez** (Daniel Sanchez Herranz, 2009) designed a solar water heating system for an existing residential building in Zaragoza, Spain. The design had to meet the Spanish mandatory regulation which requires that new and existing buildings have to meet part of the energy demand for heating water by means of a solar thermal system.
He estimated the building heating demand using Spanish regulation "CTE, HE, 4-4 table 3.1" and used the estimate to size the solar water heating system which included number of solar collectors and storage tanks (accumulators).
The study provided specifications of the solar water heating system elements including the solar panels, storage tanks, circulating pump and controls. The specifications of the system elements is relevant to this study in the development of the bill of quantities for the proposed installation of an integrated solar and steam system. The study determined the energy savings that would be realized by using solar energy and corresponding reduction of $CO_2$ emissions.
The economic study covered the investment cost and simple payback period. The projected investment cost was 62,160€ whereas the annual savings were 2,846 € per annum leading to a simple payback period of 21.83 years. The projected $CO_2$ emission reduction amounted to 13,783 kg per annum.

**Jennifer McNulty** (McNulty, 2013) conducted an investigation quantifying efficiencies and losses for the underperforming domestic hot water system of a 40-bed care home in Orkney, United Kingdom. Domestic hot water was provided by a hybrid heat pump and oil boiler system. The geothermal heat pump supplied heat to water contained in a pre-heat cylinder, which subsequently supplied the main domestic hot water cylinder, where an oil boiler was used to inject additional heat to raise the water temperature to 60°C.
The investigation comprised of a detailed literature review, a period of preliminary analysis, an on-site inspection and a final phase of analysis examining all of the data obtained throughout the process. The boiler combustion efficiency was also determined

.The results of the investigation were used to identify the faults in the hot water system and to determine the modifications necessary to correct them.

The electrical energy usage and the fuel oil usage were obtained from existing data and the amount of water monitored using a mechanical water meter in order to work out the energy intensity.

The study determined the measures that needed to be put in place so as to improve system efficiency, the cost of implementing the measures and the associated cost savings (McNulty, 2013). The findings are useful to this study which also involves determination of boiler combustion efficiency

**Dagim Kebede** (Kebede, 2016) carried out a study entailing the design and analysis of a solar thermal system for hot water supply to Minilik II Hospital new building in Ethiopia. The selected solar collector and water storage tank were designed based on the amount of hot water demand by the hospital throughout the day. An investigation was also carried out regarding the hot water distribution system.

Transient performance of the system was computed using a numerical heat transfer model of a single glass cover flat plate collector. Various parameters were obtained from local solar water collector manufacturers and the meteorological station. Based on the annual contribution of the heating load, energy savings ,the investment cost and payback period were determined. In the study, reference was made to the guidelines for hot water demand in hospitals by the institute of plumbing, United Kingdom as per table A4-1 in Appendix A4. Reference has been made to the same table in this study.

The economic analysis covered the investment cost and simple payback period of the solar water heating system. The study showed that for Minilik hospital, for a total daily hot water demand of 30.475m$^3$, 108 collectors with a storage capacity of 18.3m$^3$ were required with an initial capital cost of 1,864,054 Birr (1 US$ =41.5 Ethiopian Birr) equivalent to US$ 44,917. The life cycle cost saving of the investment (solar water heating system) was 1,869,571 Birr (US$ 45,050). The simple payback period was 2.2 years. A similar life cycle cost assessment has been conducted in this study.

**Sofie Lang** (Lang, 2010) conducted a study at Lund University in collaboration with "AB Regin" in Landskrona". "AB Regin" wanted to establish whether their existing controller platforms could be applied in a control system for boilers.

In this study, the key paramters associated with the combustion process were reviewed and different types of fuel commonly used in boilers assessed and compared. The most common boiler designs were documented and definitions relating to boilers explained.

An empirical study was done to establish the techniques available to improve boiler efficiency. The different techniques, control systems and the necessary design changes were described in detail. The measurement instruments required in the improvement techniques were also determined and documented .

Case studies were conducted to determine which techniques are used in practice to improve boiler efficiency. A control system was then designed and simulated.

The case studies confirmed that the economic viability of the various control techniques were dependent upon the size of the boiler system. Control of the percentage of oxygen in flue gas was used to improve boiler efficiency in small scale systems whereas the larger scale systems used a wide range of control techniques. The reason for this was that the investment cost of many of the control systems was high and the payback period for small scale systems was too long as fuel usage was low. The review on the different methods available for boiler efficiency improvement were found useful and have also been cited in this study.

# Chapter 3: Research Methodology

## 3.1 Introduction

The aim of this study was to estimate the energy demand for water heating in a hospital and the integration of solar thermal energy with the existing steam boiler heating system. In this chapter a presentation is made of the methods and procedures that were used in the study

## 3.2 Hot water Demand

The current method of hot water generation was reviewed and the key task was to estimate the hot water demand. Historical data on cold and hot water usage and corresponding bed occupancy was obtained from company records. The records were based on water flow measurements using mechanical turbine meters, water bills from the water supply company and electricity bills. Hot water in Hospital H1 and hospital H2 is obtained by transfer of heat from steam to cold water in a calorifier whereas it is generated in an electrically heated calorifier in hospital H3

The measurements to determine the hot water energy demand in hospital H1 were made by measuring the cold water flow rate into the calorifier and its temperature rise across the calorifier. In addition, the temperature of steam into the calorifier was measured.

Hospital H1 had a bed capacity of 225 while the other hospitals, hospital H2 and hospital H3 had bed capacities of 176 and 103 beds, respectively. Actual water flow measurements were conducted at Hospital H1 only.

### 3.2.1 Hot water demand by measurement at Hospital H1

Hot water flow demand was determined through measurement using an ultrasonic flow meter, model FDT-21 made by Omega Engineering Inc. USA and the purpose of measurements was to validate the historical data.

The specification for the ultrasonic flow meter is summarised in Table 3.1.

*Table 3-1- Specification for ultrasonic flow meter*

| **Parameter** | **value** |
|---|---|
| Linearity | 0.5% |
| Repeatability | 0.2% |
| Accuracy | +/- 1 % of reading at rates > 0.2 m/s |
| Velocity | +/- 32m/s |
| Pipe size | 20mm to 6000mm |
| Liquid types | water |

The transit time ultrasonic flow meter utilizes two transducers that function as both ultrasonic transmitters and receivers. The transducers are clamped on the outside of a pipe that is transporting water at a specific distance from each other depending on the material and diameter of the pipe. The flow meter operates by alternately transmitting and receiving a frequency modulated burst of sound energy between the two transducers and measuring the transit time that it takes for sound to travel between the two transducers.

A comparison is made of upstream and downstream measurements. If there is no flow, the travel time will be the same in both directions. When flow is present, sound moves faster if traveling in the same direction and slower if moving against. The difference in the upstream and downstream measurements taken over the same path is translated into flow

Figure 3.1 shows a typical mounting configuration of transducers and flow meter (microprocessor) on a pipe transporting water.

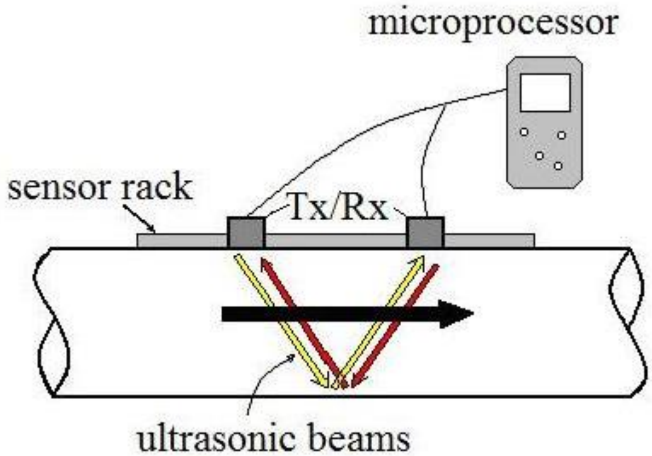



*Figure 3-1 Ultrasonic flow transducers (Tx/Rx) and a microprocessor (meter)*

Actual measurements to determine flow rate were carried out from 17/08/19 to 23/08/19 at Hospital H1 using the ultrasonic flow meter. Transducers were mounted on the water steel pipe using steel fasteners and chains and connected to the ultrasonic flow meter using electric cables. The spacing of the transducers was set according to guidelines in the manufacturer's catalogue and the ultrasonic flow meter was then able to show the velocity (m/s) and accumulated flow ($m^3$) at intervals of 1 hour. The set-up of the instruments for measurement is given in Figures 3.2, 3.3 and 3.4.

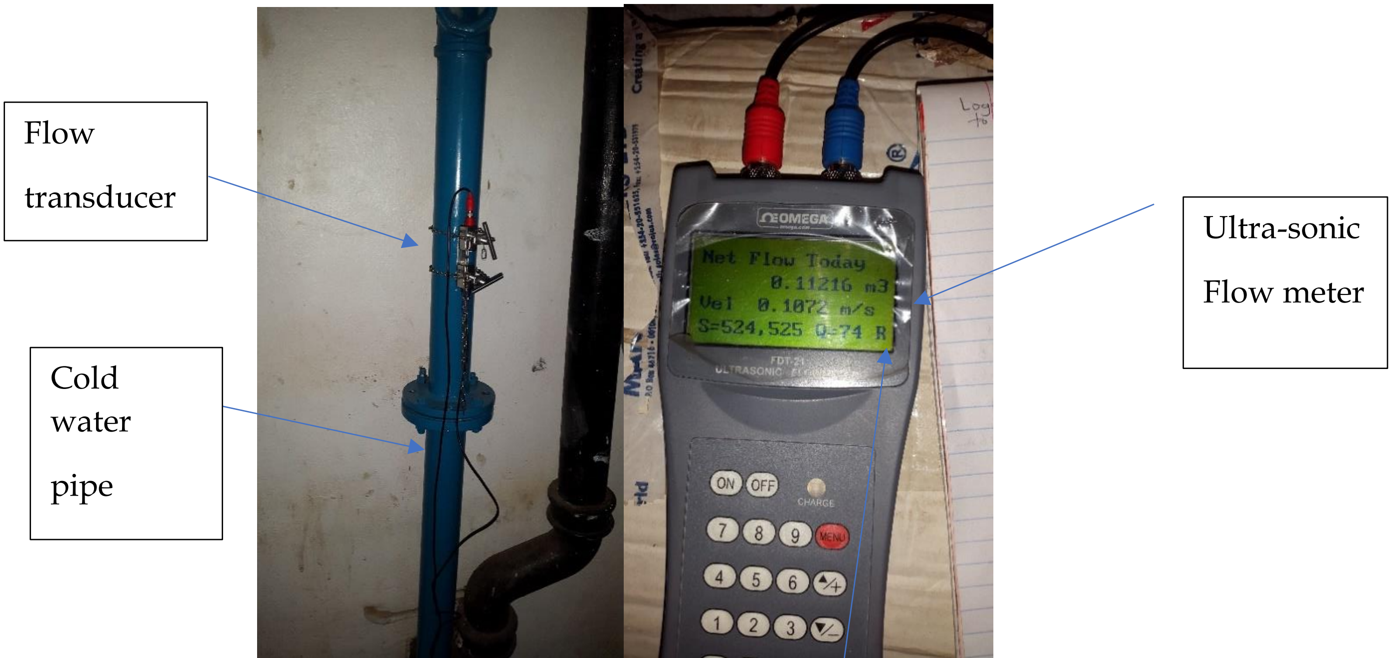



*Figure 3-2– Transducers mounted on a water pipe and connected to the "OMEGA FDT-21 ultrasonic flow meter*


*Figure 3-3 shows the magnified view of the ultrasonic flow meter*


*Figure 3-4 Calorifiers that supply hot water to the wards at hospital H1*

The figure shows the calorifiers in use at the hospital. Cold water is delivered into the calorifier at the bottom of the unit. Steam is delivered into the heat exchanger of the calorifier through a steam flow regulator depending on the temperature requirements at the end use facility such as showers. Steam will discharge enthalpy of evaporation to the cold water and then discharge as condensate through a steam trap at the bottom of the calorifier heat exchanger.

### 3.2.2 Hot water demand at hospital H2

The hospital has a bed capacity of 176 and uses steam heated calorifiers as per figure 3.5 to generate and store hot water. An assessment was made of the existing water and electricity bills from the utility companies and cold water consumption records in respect of local hospital H2

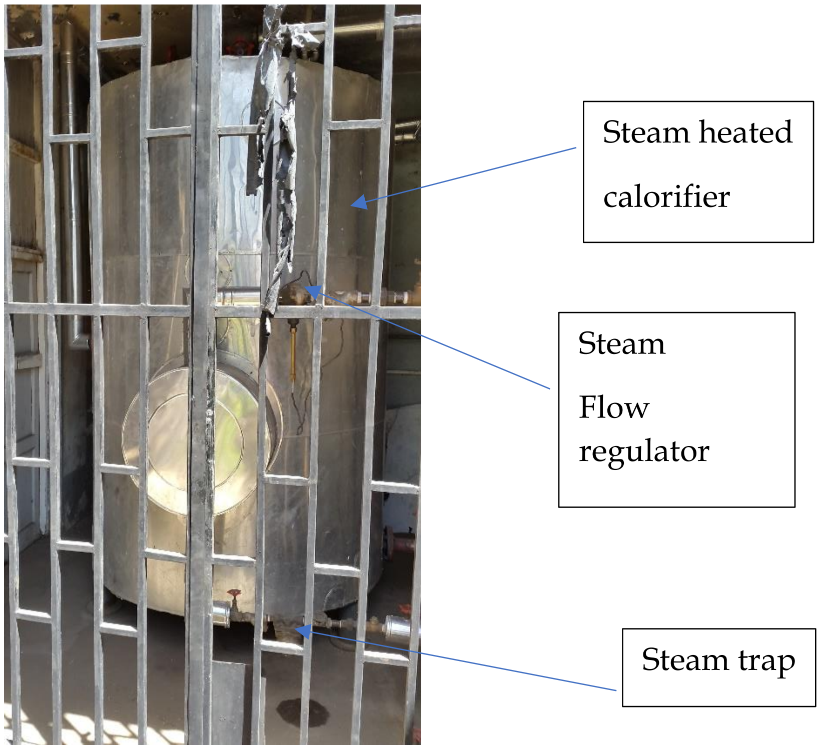



*Figure 3-5- A calorifier at hospital H2*

### 3.2.3 Hot water demand at hospital H3

The hospital has 4 No. calorifiers and each calorifier is equipped with four electric heaters rated at 3kW.The calorifiers are located on separate floors as detailed below:

- Ground floor – one calorifier serving ground floor facilities
- $2^{nd}$Floor – one calorifier serving $2^{nd}$ floor wards
- $3^{rd}$ Floor – two calorifiers serving $1^{st}$ and $3^{rd}$ floors

The energy consumption profile for the heaters (calorifiers) was measured using a power logger. Figure 3.6 below shows one of the electrically heated calorifiers at the hospital

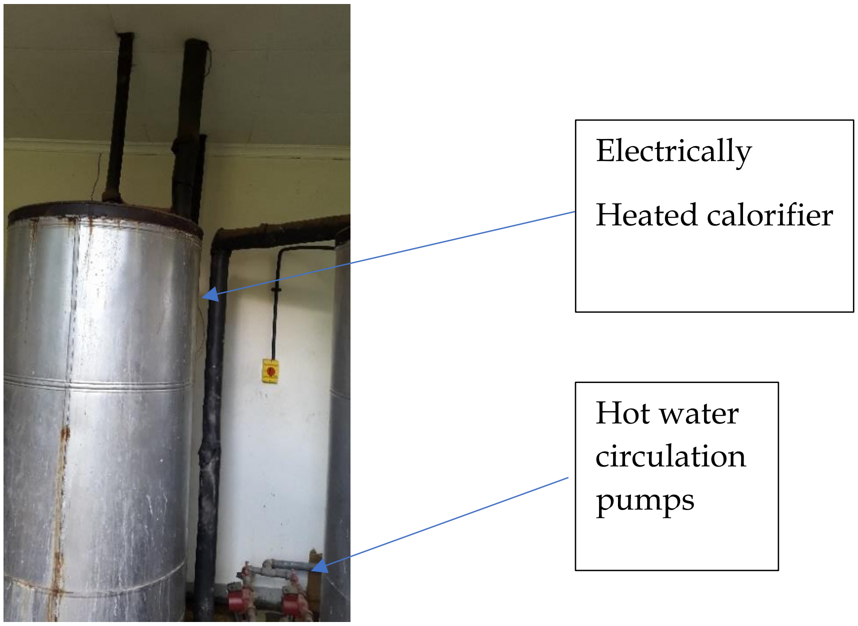



*Figure 3-6 An Electrically heated calorifier at hospital H3*

## 3.3 Determination of boiler combustion efficiency at Hospital H1:

Boiler fuel consumption data was obtained from records at Hospital H1. A flue gas analyser was used to measure the boiler combustion efficiency directly. The parameters measured by the flue gas analyser included: % oxygen ($O_2$) in flue gas; % carbon monoxide (CO) in flue gas; % carbon dioxide ($CO_2$) in flue gas and Ambient and flue gas temperatures. The flue gas analyser used was "TESTO Model 330-2, the specifications of which are given in Table 3.2.

*Table 3-2- Specifications of the TESTO Model 330-2 flue gas analyzer.*

| | |
|---|---|
| **Measurement of % oxygen ($O^2$) in flue gas** | |
| Measuring range | 0 to 21% by Volume |
| Accuracy | +/- 0.2% by volume |
| Resolution | 0.1% by volume |
| Reaction time | < 20 sec. |
| **Measurement of % carbon monoxide (CO) in flue gas** | |
| Measuring range | 0 to 8000 ppm |
| Accuracy | +/- 10 ppm or 10% of mv (0 to 200 ppm)<br>+/- 10% of mv (2001 to 8000 ppm) |
| Resolution | 1 ppm |
| Reaction time | < 60 sec. |
| **Measurement of % carbon dioxide ($CO^2$) in flue gas** | |
| Measuring range | 0 to 10000 ppm<br>0 to 1% |
| Accuracy | +/- 50ppm or +/- 2% of mv (0 to 5000ppm)<br>+/- 100ppm or +/- 3% of mv (5001 to 10000ppm) |
| Reaction time | Approximately 35 sec. |
| **Measurement of Temperature** | |
| Measuring range | - 40º to 2192ºF /-40º to + 1200ºC |
| Accuracy | +/- 1 ºF (32º to 212 ºF) / +/- 0.5ºC (0 to + 100ºC)/ +/- 0.5% of mv (remaining range). |

Figure 3.7 shows the flue gas analyser set up to take a sample of flue gas from the chimney of one of the boilers. The sample of flue gas was taken by a probe in the chimney that was connected to the flue gas analyser through a flexible tube.


*Figure 3-7- The flue gas analyzer set up to take a sample of flue gas from the boiler chimney*

*Figure 3-8 shows a magnification of the digital display of the flue gas analyzer in Figure 3.7*

The digital display of the flue gas analyzer shows as follows:

- 27.9 °C AT – i.e. Ambient temperature
- 208.5°C FT – i.e. flue gas temperature
- 6.3% $O_2$ – i.e. % oxygen in flue gas.
- 1 ppm CO - i.e. 1 part per million of Carbon monoxide in flue gas

### 3.4 Cost of producing hot water in the current system in Hospital H1

The hot water demand obtained from section 3.2, the boiler efficiency from section 3.3 and the cost of fuel per litre were used to evaluate the cost of producing hot water. The procedure to determine the heating demand and the cost of producing hot water was as follows:

Determine average heating demand (Q1) as follows:

$$Q_1 = V_1 \times \rho \times C_p \times (T_2 - T_1) \quad 3.1$$

Where:

$Q_1$- Average heating demand over a 24 hour period (kJ)

$V_1$ - Cumulative flow over a 24 hour period ($m^3$)

ρ - Density of water ($kg/m^3$)

$C_p$- Specific heat capacity of water (kJ/kg)

$T_1$ - Temperature of cold water into the calorifier

$T_2$ -Temperature of water leaving the calorifier to end uses

The corresponding steam usage over the same period was determined as follows (Wayne C. Turner, 2007)

$$Q_2 = M_2 \times h_{fg} \quad 3.2$$

Where:

$Q_2$ -Heat discharged by steam at the calorifier assuming 100% calorifier efficiency (kJ)

$M_2$ -Mass of steam used at the calorifier (kg)

$h_{fg}$ -Enthalpy of evaporation (kJ/kg) at steam supply temperature / pressure.

The corresponding fuel usage ( $F_k$ ) at the boiler over the same period was determined as follows (Wayne C. Turner, 2007):

$$F_k = \frac{Q_3}{C_v} \quad 3.3$$

$$F_1 = \frac{F_k}{S_g} \quad 3.4$$

Where:

$Q_3$ - Heat supplied by fuel to the boiler that corresponds to amount of steam

$F_k$ -Kg of fuel used

$F_1$ -Litres of fuel used

$S_g$.-Specific gravity of fuel.

$C_v$ - Calorific value of the fuel (Kj/kg)

$C_f$ -Cost of fuel per liter.

$C_c$ - Cost of cold water from Nairobi county government

$C_h$ – cost of heating water

$C_t$ – Total Cost of producing hot water

$$C_h = C_f \times F_1 \quad 3.5$$

$$C_t = C_c + C_h \quad 3.6$$

## 3.5 Sizing of solar panels and specification of the integrated steam and solar water heating system:

The size and quantity of solar panels to contribute 40% of the total heating load (demand) was determined by considering the heating demand. Several catalogues for solar water heaters were reviewed in order to appreciate the common approach to determining solar panel size for a given hot water demand.

The catalogues which were reviewed are as follows:

The catalogue for "Dayliff Ultrasun UF flat plate solar water heaters" from Davies and shirtliff (a local dealer); the catalogue for "solimpeks solar water heaters" and the catalogue for "Bosch solar water heaters". The catalogue for "Dayliff Ultrasun UF flat plate solar water heaters "was adopted for application in this study.

### 3.6 Economic evaluation of the integrated steam and solar water heating system

An economic evaluation of the integrated system was carried out including life cycle cost analysis. A suitable discounting factor reflecting the commercial lending rates was used to do the analysis. Various project viability indicators were determined including: simple payback period (years), return on investment (ROI), net present value (NPV) and internal rate of return (IRR) (Paneerselvam R., 2001)

The definitions of the financial indicators are given as follows:

$$Simple\ payback\ period\ (SPBP) in\ years\ =\ the\ investment\ cost\ /\ net\ annual\ savings$$

$$The\ return\ on\ investment\ (ROI) is\ given\ as\ a\ percentage$$

$$=\ \left(\frac{Net\ annualsavings}{investment\ cost}\right) \times\ 100$$

$$Present\ value\ (P) of\ a\ future\ cashflow\ (F) = \frac{Future\ value(F)}{(1+\ I)^n}$$

$$Future\ value\ (F)\ of\ a\ present\ value\ (P)\ =\ Present\ value\ (P) \times\ (1\ + I)^n$$

Where:

I = the discount factor

n = No. of years from present (Normally equal to the economic or useful life of a project)

Net present value (NPV) is the sum of all positive cash flows (savings) and negative cash flows (expenses) discounted to present value. The negative cash flows include the initial investment cost. A project is feasible if NPV is positive.

Thus,

$$NPV = Discounted\ sum\ of\ positive\ cashflows + Discounted\ sum\ of\ negative\ cashflows$$

Internal rate of return (IRR) is the discount factor that gives a net present value of Zero. This implies a discount factor that is applicable when cash inflows is equal to cash outflows. NPV and IRR can be obtained by using the interest compounding tables or Microsoft Excel. For this research, interest compounding tables were used.

# Chapter 4: Results and discussions

## 4.1 Introduction

In chapter 3, methods on how to estimate hot water demand in a hospital were presented. This chapter presents the findings and discussion of the outcomes of the project.

## 4.2 Hot water demand.

In chapter 3, methods and procedures were outlined on how to determine hot water demand. In this section the historical data and actual measurements are presented. During the baseline period (January to December, 2018), the hospital consumed approximately 432,413 litres of automotive gas (diesel) oil equivalent to 16,809 GJ, at a cost of ksh. 37,126,980 (US$ 309,391) to generate hot water and steam for 64,451 inpatient bed-days. The fuel consumption resulted in the release of 1,146 tons of carbon dioxide ($CO_2$). The emissions from the boiler can be reduced by improving boiler efficiency.

### 4.2.1 Hot water demand at Hospital H1 from historical data

The data in Table 4.1 was obtained from historical records.

*Table 4-1-Historical data on water consumption and bed occupancy for hospital H1*

| Period 2018 | No. of days | Bed occupancy | | Water consumption | |
|---|---|---|---|---|---|
| | | Rate (%) | Inpatient bed days | Cold ($M^3$) | Hot ($M^3$) |
| Jan | 31 | 80% | 5580 | 1730 | 1,046 |
| Feb | 28 | 83% | 5229 | 1565 | 972 |
| March | 31 | 80% | 5580 | 1679 | 1,030 |
| April | 30 | 79% | 5333 | 1678 | 1,036 |
| May | 31 | 80% | 5580 | 1722 | 1,050 |
| June | 30 | 80% | 5400 | 1658 | 1,020 |
| July | 31 | 82% | 5720 | 1740 | 1,065 |
| Aug | 31 | 83% | 5789 | 1573 | 1,063 |
| Sept | 30 | 84% | 5670 | 1525 | 1,027 |
| Oct | 31 | 83% | 5789 | 1621 | 1,056 |
| Nov. | 30 | 84% | 5670 | 1675 | 1,029 |
| Dec. | 31 | 85% | 5929 | 1759 | 1,065 |
| Total | 365 | 9.83 | 67268 | 19926 | 12459 |
| **Average** | **30.4** | **82%** | **5,606** | **1,660** | **1,038** |

- Column 3 shows the bed occupancy rate as a percentage i.e Number of beds occupied as a percentage of the hospital bed capacity
- Column 4 shows the bed occupancy (inpatient bed days). A bed-day is a day during which a person is confined to a bed and in which the patient stays overnight in a hospital as defined in the OECD health data extract in Appendix A7

The historical data was analyzed and summarized in Table 4.2 based on an average water cost of Ksh. 655/m³ (USD 6.4/m³) as provided by the hospital.

*Table 4-2 Historical data showing bed occupancy and hot water usage intensity for hospital H1*

| **Period, 2018** | **Hot water consumption (M³)** | **Cost of cold of cold water** | | | **Water use Intensity (litres/IbD** | |
|---|---|---|---|---|---|---|
| | | **(kshs)** | **(ksh/m³)** | **(US$/m³)** | **Cold water** | **Hot water** |
| Jan | 1,046 | 67,990 | 660 | 6.4 | 310 | 187 |
| Feb | 972 | 63,180 | 613 | 6.0 | 299 | 186 |
| March | 1,030 | 66,950 | 650 | 6.3 | 301 | 185 |
| April | 1,036 | 67,340 | 654 | 6.3 | 315 | 194 |
| May | 1,050 | 68,250 | 663 | 6.4 | 309 | 188 |
| June | 1,020 | 66,300 | 644 | 6.2 | 307 | 189 |
| July | 1,065 | 69,225 | 672 | 6.5 | 304 | 186 |
| Aug | 1,063 | 69,095 | 671 | 6.5 | 272 | 184 |
| Sept | 1,027 | 66,755 | 648 | 6.3 | 269 | 181 |
| Oct | 1,056 | 68,640 | 666 | 6.5 | 280 | 182 |
| Nov. | 1,029 | 66,885 | 649 | 6.3 | 295 | 181 |
| Dec. | 1,065 | 69,225 | 672 | 6.5 | 297 | 180 |
| Total | 12459 | 809,835 | 7,862 | 76.3 | 3,558 | 2224 |
| **Average** | **1,038** | **67,486** | **655** | **6.4** | **296** | **185** |

Sample calculations:

i) $Inpatient\ bed\ days\ =\ No\ of\ days\ in\ a\ month\ \times$ $Bed\ occupancy\ rate\ (\%) \times\ bed\ capacity\ e.g$

$$31 \times\ (80/100) \times 225 = 5580$$

ii) $Cold\ water\ usage\ intensity\ =\ cold\ water\ consumption\ (m^3) \times$ $\frac{1000 Litres}{m^3} / No. of\ inpatient\ bed\ days\ \ e.g$

$$1730\ \times\ 1000/5580 = 310$$

iii) $Hot\ water\ usage\ intensity\ = Hot\ water\ consumption\ (m^3) \times$ $\frac{1000 Litres}{m^3} / No\ .of\ inpatient\ bed\ days\ e.g$

$$\frac{1046\ \times 1000}{5580} = 187$$

Table 4.2 shows that during the year in reference the average hot water usage intensity was 185 liters per inpatient bed day whereas the lowest and highest average water usage intensity in each month during the same year were 180 and 194 liters per inpatient bed day respectively based on historical data.

Figure 4.1 shows the hot water usage intensity for Hospital H1. It shows that the intensity reduces as the occupancy rate increases.

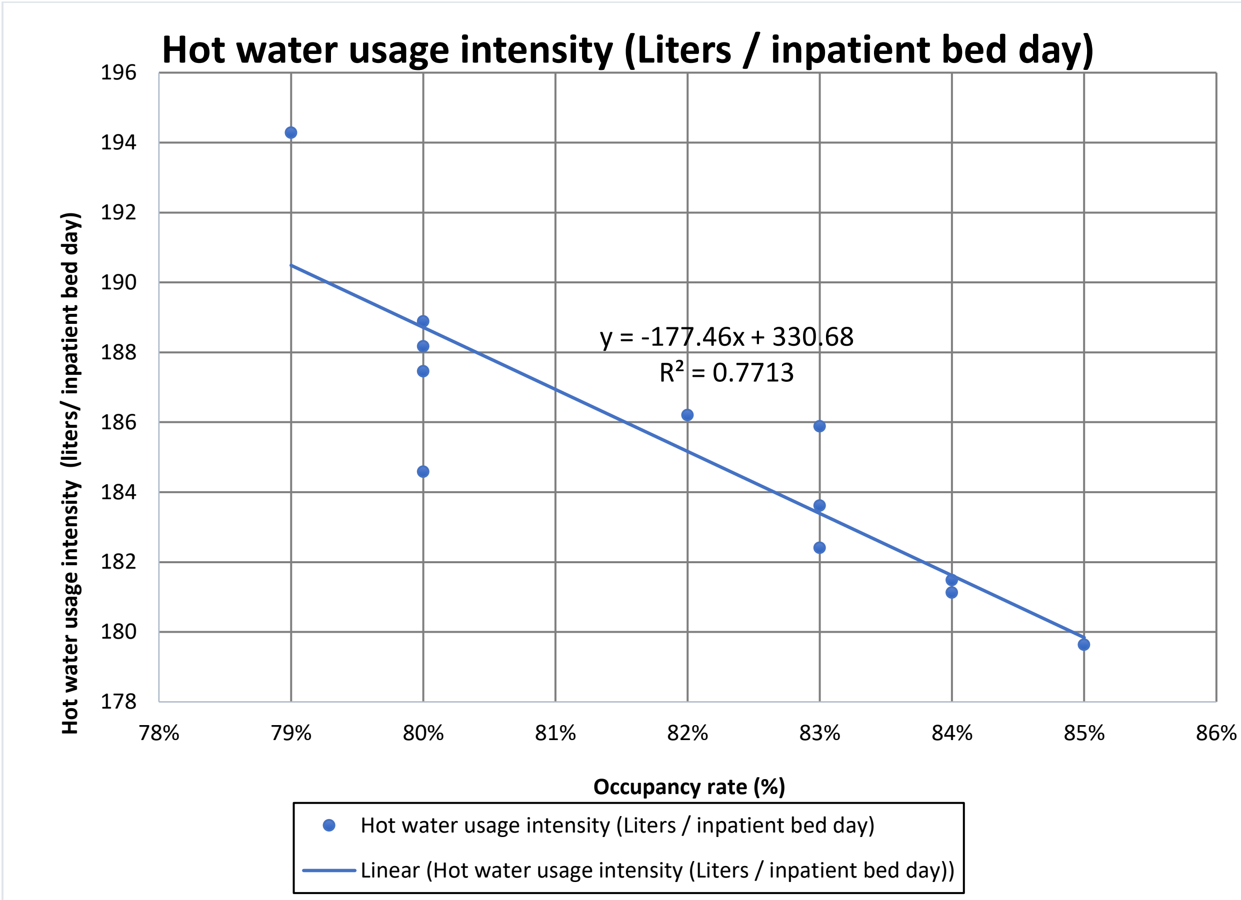



*Figure 4-1 Hot water usage intensity profile versus occupancy rate (%)-Hospital H1*

### 4.2.2 Determination of hot water demand from measurements at Hospital H1

Measurements of hot water consumption by the wards were taken using an ultrasonic flow meter for one week and the results are given in Table 4.3.

*Table 4-3– Hot water consumption measurements at hospital H1*

| **Summary of Hot water consumption for Hospital H1 obtained through measurement with an ultrasonic flow meter** | | |
|---|---|---|
| **Dates** | **Day** | **Consumption(M³)** |
| 17/08/2019 | 1 | 37.418 |
| 18/08/2019 | 2 | 33.279 |
| 19/08/2019 | 3 | 33.593 |
| 20/08/2019 | 4 | 35.791 |
| 21/08/2019 | 5 | 31.405 |
| 22/08/2019 | 6 | 34.380 |
| 23/08/2019 | 7 | 34.460 |
| **Total** | | **240.325** |
| **Average per day** | | **34.332** |
| **Bed occupancy - inpatient bed days over the period (recorded)** | | 1323 |
| **Average water usage intensity (liters per inpatient bed day)** | | 181.7 |

$$The\ average\ water\ usage\ intensity\ (liters\ per\ inpatient\ bed\ day)$$
$$= 240.325\ (m^3) \times 1000\ \left(\frac{liters}{m^3}\right)/1323\ (inpatient\ bed\ days) = 181.7.$$

Table 4.2 shows that during the year in reference the average water usage intensity was 185 liters per inpatient bed day whereas the lowest and highest average water usage intensity in each month during the same year were 180 and 194 liters per inpatient bed day respectively based on historical data

Table 4.3 indicates that the average water usage intensity based on measurements was 181.7 liters per inpatient bed day.

Therefore the value of water usage intensity obtained through measurements is within the range of the historical data and hence acceptable.

The data in Table 4.3 was used to prepare the trend chart in Figure 4.2

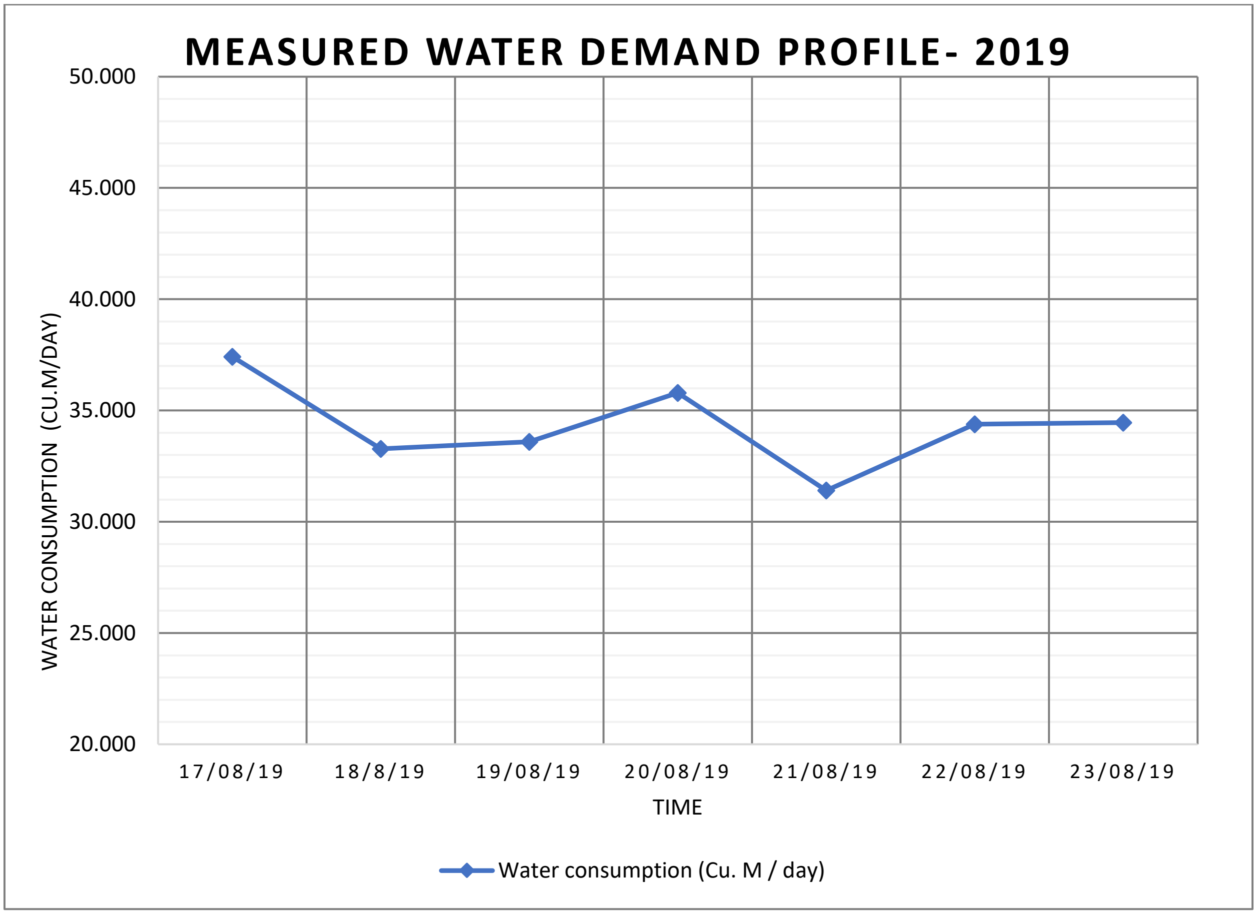



*Figure 4-2 measured water demand profile at hospital H1*

The trend chart shows that the water usage varied between 31.4 and 37.4 m$^3$/day.

The primary data is in appendix A8.

### 4.2.3 Determination of hot water demand at hospital H2 from historical data

The hospital has a bed capacity of 176 and uses steam heated calorifiers to generate and store hot water. Steam is also used in the dryers at the laundry and in steam cooking jackets at the Kitchen. The quantity of hot water used is not measured.

#### 4.2.4 Determination of hot water demand at hospital H3 from historical data

The hospital has a bed capacity of 103 and uses electrically heated calorifiers to generate and store hot water. The quantity of hot water used is not measured.

#### 4.2.5 Water demand determination using guidelines from institute of plumbing:

The hot water demand was estimated using Table A4-1 in Appendix A4 (The institute of plumbing, 2002 Edition). Table A4-1 indicates that daily hot water demand per bed for a general hospital is equal to 200 Litres .Hence daily water demand for Hospital H1 based on the guideline is 225 x 200 = 45,000 Litres. However, the measured daily demand is slightly lower at 181.7 litres per in patient bed day.

### 4.3 Hot water Energy demand

In this study, a review was made of the water, electricity and fuel consumption records of hospital H1, hospital H2 and hospital H3. Temperature measurements of cold water into the calorifiers, hot water to the end uses and live steam into the calorifiers were made using an infrared thermometer at Hospital H1.

#### 4.3.1 Hot water energy demand for Hospital H1 from historical data

The hospital generates hot water using steam boilers which are fired using automotive diesel (gas) oil. The hot water is mainly used for showers in the wards, laundry and kitchen. The steam from the boilers transfers heat to cold water through calorifiers. In addition, the dry saturated steam is also used in the dryers at the laundry and in the cooking vessels at the kitchen.The historical thermal energy data is given in Table 4.4

*Table 4-4- Historical thermal energy data at hospital H1*

| Period (2018) | No. of days | Bed occupancy | | Automotive Gas Oil Consumption | |
|---|---|---|---|---|---|
| | | % | IbD | Liters | Cost (Ksh) |
| Jan | 31 | 80% | 5580 | 34795.5 | 2,987,542 |
| Feb | 28 | 83% | 5229 | 33149 | 2,846,173 |

| | | | | | |
|---|---|---|---|---|---|
| March | 31 | 80% | 5580 | 38698 | 3,322,610 |
| April | 30 | 79% | 5333 | 35631.5 | 3,059,321 |
| May | 31 | 80% | 5580 | 39215 | 3,367,000 |
| June | 30 | 80% | 5400 | 35854.5 | 3,078,467 |
| July | 31 | 82% | 5720 | 39942.5 | 3,429,463 |
| Aug | 31 | 83% | 5789 | 38405 | 3,297,453 |
| Sept | 30 | 84% | 5670 | 39578 | 3,398,167 |
| Oct | 31 | 83% | 5789 | 32722.5 | 2,809,554 |
| Nov. | 30 | 84% | 5670 | 32478 | 2,788,561 |
| Dec. | 31 | 85% | 5929 | 31943.5 | 2,742,669 |
| Total | 365 | 983% | 67268 | **432,413** | **37,126,980** |
| **Average** | **30.4** | **82%** | **5,606** | **36,034** | **3,093,915** |

The data in Table 4.4 was analyzed and summarized in Table 4.5. Column 3 shows the bed occupancy (inpatient bed days) per month. Column 8 shows the corresponding amount of CO2 in tons released as a result of consuming the diesel per month.

*Table 4-5- Historical Thermal Energy intensity and $CO_2$ Emissions at hospital H1*

| **Period (2018)** | **Bed occupancy (IbD)** | Automotive gas oil (AGO) Consumption by the Boilers | | | | | |
|---|---|---|---|---|---|---|---|
| | | **intensity (L/IbD)** | **Litres** | **Equivalent (GJ)** | **GJ/IbD** | **Cost (Ksh)** | **Equivalent Tons CO2** |
| Jan | 5580 | 5.5 | 34795.5 | 1,353 | 0.215 | 2,987,542 | 92 |
| Feb | 5229 | 5.3 | 33149.0 | 1,289 | 0.205 | 2,846,173 | 88 |
| March | 5580 | 5.8 | 38698.0 | 1,504 | 0.227 | 3,322,610 | 103 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| April | 5333 | 5.7 | 35631.5 | 1,385 | 0.221 | 3,059,321 | 94 |
| May | 5580 | 6.0 | 39215.0 | 1,524 | 0.232 | 3,367,000 | 104 |
| June | 5400 | 5.3 | 35854.5 | 1,394 | 0.206 | 3,078,467 | 95 |
| July | 5720 | 6.4 | 39942.5 | 1,553 | 0.247 | 3,429,463 | 106 |
| Aug | 5789 | 5.7 | 38405.0 | 1,493 | 0.223 | 3,297,453 | 102 |
| Sept | 5670 | 6.2 | 39578.0 | 1,538 | 0.240 | 3,398,167 | 105 |
| Oct | 5789 | 5.2 | 32722.5 | 1,272 | 0.203 | 2,809,554 | 87 |
| Nov. | 5670 | 5.3 | 32478.0 | 1,262 | 0.206 | 2,788,561 | 86 |
| Dec. | 5929 | 5.1 | 31943.5 | 1,242 | 0.198 | 2,742,669 | 85 |
| **Total** | 67268 | **67.5** | **432,413** | **16,809** | **2.623** | **7,126,980** | **1,146** |
| **Average** | **5,606** | **5.6** | **36034.4** | **1400.7** | **0.219** | **3,093,915** | **95.5** |

Sample calculations:

i) $Inpatient\ bed\ days\ =\ No\ of\ days\ in\ a\ month\ \times$
$Bed\ occupancy\ rate\ (\%) \times\ bed\ capacity\ e.g$

$$31\ \times\ (80/100) \times\ 225 = 5580$$

ii) $Automotive\ Gas\ Oil\ (AGO) energy\ intensity\ \left(\frac{liters}{inpatient\ bed\ day}\right) =$
$Liters\ of\ AGO\ consumed\ in\ a\ month/No.of\ inpatient\ bed\ days\ \ e.g$

$$\frac{34795}{55580} = 5.5$$

iii) Conversion from Liters of AGO to GJ:

$$GJ\ of\ AGO\ =\ Liters\ of\ AGO\ \times\ Gross\ calorific\ value\ \left(\frac{KJ}{Kg}\right) \times \frac{specific\ gravity}{10^6}$$

For example, in January the Gigajoules equivalent of diesel consumed was determined as follows.

$$(34795.5\ \times 45{,}200\ \times 0.86)/10^6 = 1353$$

Equivalent tons of $CO_2$ : This is the amount of carbon dioxide released to the atmosphere due to combustion of AGO.

$$Equivalent\ tons\ of\ CO2\ =\ Fuel\ usage\ (liters) \times Conversion\ factor\ for\ CO_2$$

Again, in January the $CO_2$ equivalent of diesel consumed was determined as follows.

$$34795.5\ \times 2.65 = 92$$

*Table 4-6- Carbon dioxide conversion factors – source: UK Department for Business, Energy & industrial strategy (https/www.gov.uk/government)*

| **Carbon Dioxide Conversion Factors** | |
|---|---|
| **Fuel type** | **kg of CO2 per unit of consumption** |
| Grid electricity (kg/kwh) | 43 |
| Natural gas (kg/ton) | 3142 |
| Diesel fuel (kg/liter) | 2.65 |
| petrol (kg/liter) | 2.31 |

The analysis of the data in table 4-5 shows as follows:

- $The\ Average\ fuel\ energy\ intensity \left(\frac{GJ}{Inpatient\ bed\ day}\right) =\ 0.219$
- $The\ Average\ Cost\ of\ fuel\ energy\ \left(\frac{ksh}{Inpatient\ bed\ day}\right) = \frac{3{,}093{,}915}{5{,}606} = 551.$

### 4.3.2 Hot water Energy demand at Hospital H1 through measurements

Temperature measurements of cold water into the calorifiers, hot water to the end uses and live steam into the calorifiers were made using an infrared thermometer at Hospital H1. The calorifiers were supplying hot water to the wards only. The measurements were taken to validate historical data. The measurements yielded the data in Table 4.7 and Table 4.8.

*Table 4-7– Hot water flow measurements at hospital H1*

| **Summary of Hot water consumption for the Hospital** | | |
|---|---|---|
| **Duration /Dates** | **Day** | **Consumption($M^3$)** |
| 17/80/2019 | 1 | 37.418 |
| 8/18/2019 | 2 | 33.279 |
| 8/19/2019 | 3 | 33.593 |
| 8/20/2019 | 4 | 35.791 |
| 8/21/2019 | 5 | 31.405 |
| 8/22/2019 | 6 | 34.380 |
| 8/23/2019 | 7 | 34.460 |
| Total | | 240.325 |
| Average per day (**$M^3$**) | | 34.332 |
| Amount per annum(**$M^3$**) | | 12,530 |

*Table 4-8– Temperature measurements at Hospital H1*

| **Date** | **Time** | **T1 (⁰C)- Cold Water Into Calorifier** | **T2 (⁰C)- Hot Water From Calorifier** | **Temperature Difference (⁰C)** |
|---|---|---|---|---|
| 8/10/2019 | 12 Noon | 23.7 | 55.2 | 31.5 |
| | 1pm | 22.9 | 56.4 | 33.5 |
| | 2pm | 23.2 | 59.2 | 36 |
| | 3pm | 23.8 | 58.3 | 34.5 |
| | 4pm | 23.6 | 57 | 33.4 |
| 8/11/2019 | 11am | 24.6 | 58.3 | 33.7 |
| | 12noon | 24.8 | 57.6 | 32.8 |
| | 1pm | 24.3 | 58.9 | 34.6 |
| | 2pm | 24.1 | 58.4 | 34.3 |
| | 3pm | 24.5 | 56.8 | 32.3 |
| | 4pm | 24.3 | 48.2 | 23.9 |
| | 5pm | 25.4 | 60.8 | 35.4 |
| 8/18/2019 | 4pm | 28.4 | 60.6 | 32.2 |
| | 5pm | 28.7 | 60.9 | 32.2 |
| 8/19/2019 | 3pm | 28.5 | 58.7 | 30.2 |
| | 4pm | 28.6 | 57.6 | 29 |
| **Total** | | **403.4** | **922.9** | **519.5** |
| **Average** | | **25.2** | **57.7** | **32.5** |

Temperature of steam into calorifier was 165⁰C

Pressure of steam into calorifier was 6 bar gauge (7 bar absolute).

### 4.3.3 Cost of producing hot water in the current system in Hospital H1.

The hot water demand obtained from section 4.1 and the boiler efficiency from section 4.3 and the cost of fuel per litre were used to determine the cost of hot water production.

The procedure and formulae to determine the heating demand and the cost of hot water production were given in chapter 3 and have been applied in this section.

The key design parameters used in the analysis to determine the cost of water heating are given in Table 4.9:

*Table 4-9– key design Parameters to determine cost of water heating*

| | |
|---|---|
| Design temperature (°C) of water into calorifier (lowest during cold season)- T1 | 15 |
| Design temperature (°C) of water out of calorifier(to avoid legionella disease)- T2 | 60 |
| Measured water flow rate ($m^3$) | 34.332 |
| Steam pressure at entry to calorifier (psi) | 88 |
| steam pressure at entry to calorifier (bar-g) | 6 |
| Temperature (°C) of steam into calorifier | 165 |
| Enthalpy of evaporation at 6 bar (kj/kg) -$h_{fg}$ | 2066 |
| Measured gross boiler efficiency (%) | 85.3 |
| calorific value of automotive diesel (AGO)- (kj/kg) | 45,200 |
| specific gravity of AGO | 0.86 |
| Cost of diesel (ksh/ Liter). | 85.86 |
| No. of days per annum | 365 |
| **1 US $ = ksh 103** | |

**Analysis of the measurements:**

Average heating demand (Q1) was determined as follows:

$$Q_1 = V_1 \times \rho \times C_p \times (T_2 - T_1)$$

$$Q1\ (kj) = 34.332 \times 1000 \times 4.19 \times (60 - 15) = 6{,}473{,}317$$

Where:

$V_1$ = 34.332

$T_1$= 15

ρ = 1000

$T_2$ = 60

$C_p$ = 4.19

$Q_2 = M_2 \times h_{fg} = Q_1$ = **6,473,317 (**Assuming 100% calorifier efficiency)

This implies that $M_2 = Q_2 / h_{fg}$ = **6,473,317 /** 2066 = 3,133 kg

$Q_3 = Q_2$ / Boiler efficiency = **6,473,317 /0.853 =** 7,588,883 kJ

Fuel per day $= F_k = \frac{Q_3}{C_v}$ =7,588,883/45,200 = 167.9 kg

Fuel per annum = 167.9 x 365 = 61,282 kg

Fuel used per annum (GJ) = {kg of fuel used per annum × gross calorific value (kJ /kg) }/ 1,000,000 = (61,282 x 45,200)/ 1,000,000 = 2,770 GJ

Liters of fuel per day = $F_1 = F_k / S_g$ = 167.9/0.86 = 195.2 Litres

Liters of fuel per annum = 195.2 x 365 = 71,258 Litres

Cost of fuel used (ksh per annum) for water heating = 71,258 x 85.86 = Ksh. 6,118,215

Cost of fuel used (US$ per annum) for water heating = 6,118,215/103 = US$ 59,400

Total inpatient bed days per annum = 67,268 days

The analysis shows as follows:

- The energy intensity (GJ/ Inpatient bed-day) =2770/ 67,268 = 0.0412
- Cost of thermal energy (Ksh/ inpatient bed day) = 6,118,215 / 67,268 = Ksh. 91
- Cost of hot water production (Ksh /$m^3$) = 6,118,215 /12530 = Ksh 488

It is important to ensure high boiler efficiency whether heating by steam or in an integrated scenario with solar water heaters. The amount of heat transferred from steam to cold water at the calorifiers depends on the calorifier efficiency. The efficiency of the calorifiers depends on the condition of the heat exchange surfaces and the insulation of the vessel. The configuration of a typical calorifier is given in figure A4-2 in Appendix A.4.3

### 4.3.4 Energy demand for hot water at hospital H2

Hot water is currently generated using steam boilers which are fired using fuel oil (Heavy furnace oil). The steam from boilers is used in calorifiers to heat cold water for the wards, laundry and kitchen. Steam is also used directly in the laundry equipment and in the kitchen cooking vessels. Historical data on energy consumption is given in Table 4.10.

*Table 4-10- historical thermal energy data for hospital H2*

| **Month (2018)** | **No. of days in month** | **Occupancy as % of bed capacity** | **Inpatient bed days** | **Usage of F.O (lts)** | **Total cost of F.O (ksh)** |
|---|---|---|---|---|---|
| January | 31 | 63% | 3437 | 15,600 | 1,170,000 |
| February | 28 | 72% | 3548 | 15,600 | 1,170,000 |
| March | 31 | 75% | 4092 | 16,000 | 1,200,000 |
| April | 30 | 70% | 3696 | 18,600 | 1,395,000 |
| May | 31 | 69% | 3765 | 18,000 | 1,350,000 |
| June | 30 | 66% | 3485 | 13,550 | 1,016,250 |
| July | 31 | 75% | 4092 | 21,500 | 1,612,500 |
| August | 31 | 78% | 4256 | 15,700 | 1,177,500 |
| September | 30 | 81% | 4277 | 22,100 | 1,657,500 |
| October | 31 | 82% | 4474 | 19,000 | 1,425,000 |
| November | 30 | 75% | 3960 | 17,100 | 1,282,500 |
| December | 31 | 77% | 4201 | 16,700 | 1,252,500 |
| Total | 365 | 8.83 | 47,282 | 209,450 | 15,708,750 |
| **Average** | 30 | 73.6% | 3,940 | 17,454 | 1,309,063 |

Column 4 shows the bed occupancy (inpatient bed days). The data was analysed and has been summarised in Table 4.11. The table provides historical data with energy intensity and $CO_2$ emissions

*Table 4-11– Historical data with energy intensity and $CO_2$ emissions for hospital H2*

| **Month (2018)** | **Inpatient** | **Fuel oil Energy intensity** | **Fuel oil Energy intensity** | **Fuel Oil** |
|---|---|---|---|---|

| | bed days | GJ/IbD | Liters/IbD | Usage (lts) | Equivalent (GJ) | Total cost of F.O (ksh) | Equivalent Tons CO2 |
|---|---|---|---|---|---|---|---|
| Jan-18 | 3437 | 0.189 | 4.5 | 15,600 | 651 | 1,170,000 | 41 |
| Feb | 3548 | 0.183 | 4.4 | 15,600 | 651 | 1,170,000 | 41 |
| March | 4092 | 0.163 | 3.9 | 16,000 | 667 | 1,200,000 | 42 |
| April | 3696 | 0.210 | 5.0 | 18,600 | 776 | 1,395,000 | 49 |
| May | 3765 | 0.199 | 4.8 | 18,000 | 751 | 1,350,000 | 48 |
| June | 3485 | 0.162 | 3.9 | 13,550 | 565 | 1,016,250 | 36 |
| July | 4092 | 0.219 | 5.3 | 21,500 | 897 | 1,612,500 | 57 |
| August | 4256 | 0.154 | 3.7 | 15,700 | 655 | 1,177,500 | 42 |
| Sept | 4277 | 0.216 | 5.2 | 22,100 | 922 | 1,657,500 | 59 |
| Oct | 4474 | 0.177 | 4.2 | 19,000 | 793 | 1,425,000 | 50 |
| Nov | 3960 | 0.180 | 4.3 | 17,100 | 713 | 1,282,500 | 45 |
| Dec | 4201 | 0.166 | 4.0 | 16,700 | 697 | 1,252,500 | 44 |
| Total | 47,282 | 2.22 | 53.2 | 209,450 | 8,738 | 15,708,750 | 555 |
| **Average** | 3,940 | 0.185 | 4.4 | 17,454 | 728 | 1,309,063 | 46 |

The table parameters were determined as follows;

$$The\ average\ Fuel\ energy\ intensity\ \left(\frac{GJ}{Inpatient\ bed-day}\right) = 8738/47282 = 0.185$$

$$Cost\ of\ Fuel\ \left(\frac{ksh}{Inpatient\ bed\ day}\right) = \frac{15{,}708{,}750}{47{,}282} = Ksh. 332.$$

$$Cost\ of\ Fuel\ \left(\frac{US\$}{Inpatient\ bed\ day}\right) = \frac{332}{103} = US\$\ 3.22.$$

### 4.3.5 Energy demand for hot water at hospital H3

The Hospital uses only electrical energy for all its functions. The electricity is supplied from the national Grid by the Kenya Power Company and a diesel power generator is available to cater for power interruptions. Part of the electrical energy is used for water heating for the wards. The data obtained from historical records for hospital electrical energy consumption is given in Table 4.12:

*Table 4-12– Electrical energy consumption data for hospital H3*

| **Period (2018)** | **days** | **Hospital occupancy** | | **Electrical Energy intensity** | | **Electrical Energy** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **%** | **IbD** | **(kWh/IbD** | **(GJ/IbD** | **Total (kWh)** | **Equivalent (GJ)** | **Total Demand (kVA)** | **Total Cost (Ksh)** |
| Jan | 31 | 70% | 2,235 | 44.1 | 0.159 | 98,514 | 355 | 252 | 1,752,689 |
| Feb | 28 | 78% | 2,250 | 47.2 | 0.170 | 106,260 | 383 | 274 | 2,129,639 |
| March | 31 | 83% | 2,650 | 39.0 | 0.140 | 103,345 | 372 | 263 | 1,834,437 |
| April | 30 | 80% | 2,472 | 30.3 | 0.109 | 74,799 | 269 | 269 | 1,403,539 |
| May | 31 | 75% | 2,395 | 67.8 | 0.244 | 162,276 | 584 | 260 | 2,741,283 |
| June | 30 | 86% | 2,657 | 52.0 | 0.187 | 138,190 | 497 | 281 | 2,393,036 |
| July | 31 | 80% | 2,554 | 41.6 | 0.150 | 106,260 | 383 | 274 | 2,129,640 |
| Aug. | 31 | 75% | 2,395 | 52.4 | 0.189 | 125,504 | 452 | 272 | 2,159,889 |
| Sept. | 30 | 87% | 2,688 | 39.5 | 0.142 | 106,260 | 383 | 274 | 2,129,640 |
| Oct. | 31 | 74% | 2,363 | 57.6 | 0.207 | 136,168 | 490 | 298 | 2,358,757 |
| Nov. | 30 | 75% | 2,318 | | 0.202 | 130,259 | 469 | 290 | 2,263,993 |
| Dec. | 31 | 69% | 2,203 | 57.0 | 0.205 | 125,476 | 452 | 284 | 2,259,136 |
| Total | **365** | | **29,180** | **585** | **2.105** | 1,413,311 | **5,088** | **3,291** | **25,555,678** |
| **Average** | | **78%** | **2,432** | **48.7** | **0.175** | **117,776** | **424** | **274** | **2,129,640** |

The average electrical energy intensity for the facility is 48.7kwh /Inpatient bed-day

The average electrical energy intensity for the facility is hence 0.175GJ/Inpatient bed-day

$$The\ cost\ of\ electrical\ energy\ \left(\frac{ksh}{inpatient\ bed\ day}\right) = \left(\frac{2129640}{2432}\right) = ks\ 876\ \ (8.5US\$)$$

The energy consumption profile for the heaters (calorifiers) was measured earlier using a power logger and the results are shown in the Figure 4.3.

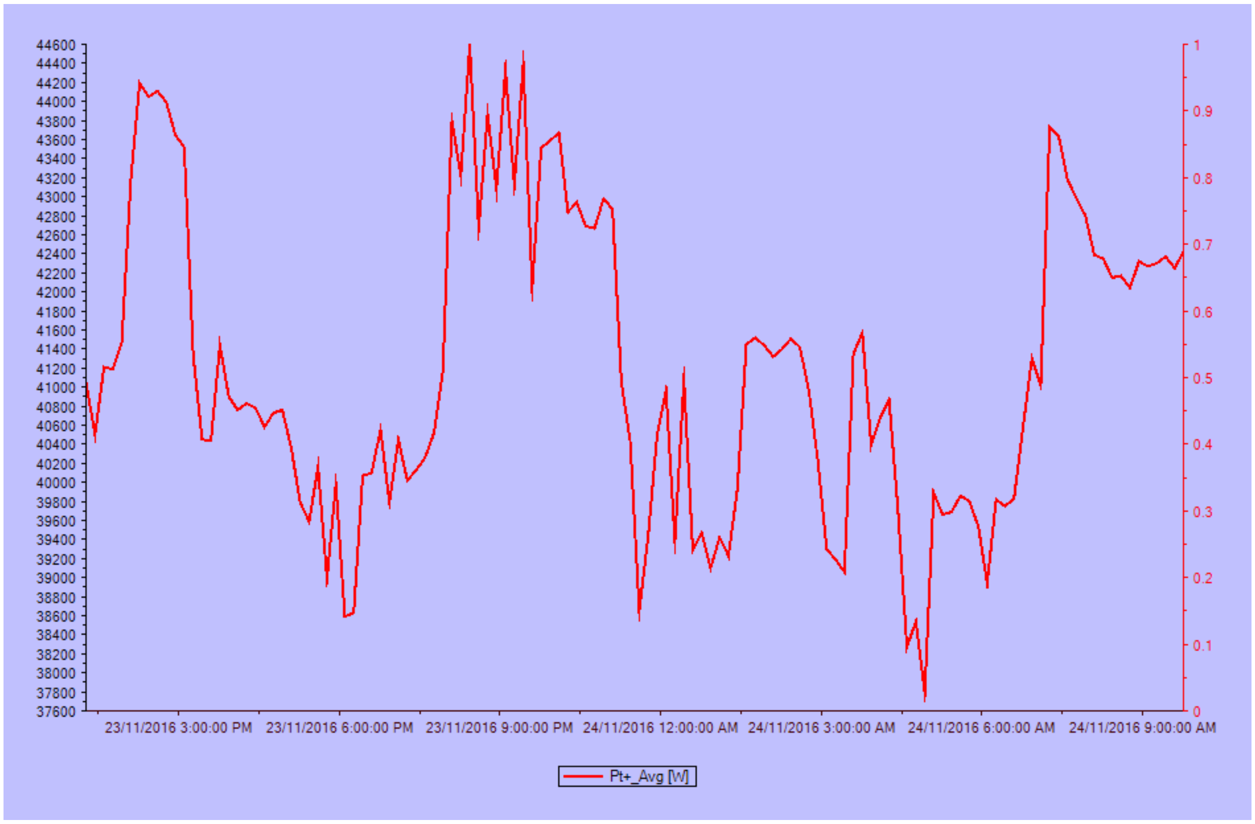



*Figure 4-3- shows power profile over a 24 hour period which is adequate to generalize power consumption pattern*

Figure 4.3 shows that demand varied between 37.6 kW and 44.6 kW over a period of 24 hours and the average power demand was approximately 41kw.  This translates to an energy intensity of 0.0443 GJ/ Inpatient bed day for water heating as detailed below. This figure is less than the value for total hospital use which is 0.175 GJ / Inpatient bed day. The cost of heating water for the wards using the electrically heated calorifiers has been determined as per Table 4.13.

*Table 4-13- Analysis of cost of heating water for the wards by the calorifiers at hospital H3*

| | |
|---|---|
| Hospital Operating hours p.a | 8760 |
| Hospital Operating days p.a | 365 |
| Electricity charges Ksh/ kWh | 9.45 |

| | |
|---|---|
| Consolidated Electricity charges Ksh/ kWh | 18.00 |
| No. of months per year | 12 |
| **Existing Situation;** | |
| The facility has 4no of calorifiers equipped with electric immersion heaters used to generate hot water for the wards. | |
| Rating of Electric immersion heaters per calorifier(kw) | 12 |
| Total rating of 4No calorifiers(kw) | 48 |
| Average power demand recorded using a power logger (kw) | **41** |

Note: 1 kWh = 3.6 MJ = 3600 KJ

The four calorifiers were equal in capacity and ran for the same period of time. The following parameters were determined as follows;

- $Energy\ consumption\ (kwh\ per\ annum) = Measured\ average\ power\ (kw) \times running\ hours\ per\ annum = 41 \times 8760 = 359{,}160$
- $Energy\ consumption\ (GJ\ per\ annum) = (359{,}160 \times 3.6)/1000 = 1293$
- $Cost\ of\ heating\ water\ (ksh\ per\ annum) = Energy\ consumption\ (kwh\ per\ annum) \times Blended\ cost\ \left(\frac{ksh}{kwh}\right) = 359{,}160 \times 18 = 6{,}464{,}880$

$$The\ average\ energy\ intensity\ for\ water\ heating\ \left(\frac{GJ}{Inpatient\ bed - day}\right) is\ = \frac{1293}{29180} = 0.0443$$

$$The\ cost\ of\ thermal\ energy\ \left(\frac{ksh}{inpatient\ bed - day}\right) = \frac{6{,}464{,}880}{29{,}180} = 221.$$

$$The\ cost\ of\ thermal\ energy\ \left(\frac{US\$}{inpatient\ bed - day}\right) = \frac{221}{103} = 2.14.$$

### 4.3.6 Comparative use of energy by the three hospitals

The comparison in energy usage in the three hospitals is summarized in table 4.14.

*Table 4-14 comparative use of fuel energy by the hospitals*

| Ser. No | Identity of hospital | Source of data | Source of energy | Average fuel energy intensity (GJ/IbD) | Cost of fuel energy (ksh/IbD) | Cost of fuel energy (US$/IbD) |
|---|---|---|---|---|---|---|
| 1 | Hospital H1 | Historical data | Automotive diesel (Gasoil) | 0.219 | 551 | 5.35 |
| 2 | Hospital H2 | Historical data | Furnace oil | 0.185 | 332 | 3.22 |
| 3 | Hospital H3 | The hospital uses electricity only | | | | |

Table 4.14 shows that the Average energy intensity (GJ/Inpatient bed day) is comparable between the two hospitals with Hospital H1 having the higher value at 0.219 whereas the lower value is at hospital H2 at 0.185. The difference is attributed to the energy efficiency measures implemented in each of the hospitals.

### 4.3.7 Comparative use of energy for water heating for the wards by the hospitals

Table 4.15 shows that the energy intensity for water heating for wards is comparable between Hospital H1 and hospital H3 at 0.0412 and 0.0443 GJ/Inpatient bed day respectively. However, the cost of heating is higher when using electrical energy at US$ 2.14 per inpatient bed day as compared to automotive diesel (gasoil) at US$ 0.88 per inpatient bed day.

*Table 4-15- Comparative Energy use for water heating for wards*

| Ser. No | Identity of hospital | Source of data | Source of energy | Average energy intensity (GJ/IbD) | Cost of thermal energy (ksh/IbD) | Cost of thermal energy (US$/IbD) |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Hospital H1 | Measurement | Automotive diesel (Gasoil) | 0.0412 | 91 | 0.88 |
| 2 | Hospital H3 | Historical data | Electrical Energy | 0.0443 | 221 | 2.14 |
| 3 | Hospital H2 | Historical data | Furnace oil | NA | NA | NA |

Legend: NA – Not available

### 4.4 Determination of boiler combustion efficiency at Hospital H1:

The hospital owns two (2 No.) Forbes Marshall diesel fired steam boilers with the following specification:

- Manufacturer: Forbes Marshall
- Model: FS3000
- Maximum continuous rating (MCR): (lb/h): 10,560
- Maximum continuous rating (MCR): (kg/h): 4,800
- Maximum allowable working pressure (psi): 150
- Hydraulic Test pressure (psi): 233

Boiler fuel consumption data was obtained from records at Hospital H1

A flue gas analyser was used to measure the boiler combustion efficiency directly. The flue gas analyser used was "TESTO Model 330-2".

The data collected through measurement is provided in Sections 4.4.1 and 4.4.2.

#### 4.4.1 Boiler No.1 flue gas measurements

The flue gas measurements in respect of boiler No.1 are provided in Table 4.16.

*Table 4-16– Boiler No.1 flue gas measurements*

| **Flue gas analysis for Boiler No.1** | | | | |
|---|---|---|---|---|
| **Parameter measured** | **Sample 1** | **Sample 2** | **sample 3** | **Average** |
| CO (ppm) | 1.0 | 2.0 | 1.0 | 1.5 |
| $CO_2$ (%) | 10.88 | 10.57 | 10.44 | 10.51 |

| | | | | |
|---|---|---|---|---|
| $O_2$ (%) | 6.03 | 6.7 | 6.9 | 6.8 |
| Flue gas Temperature °C | 208.5 | 191 | 200.8 | 195.9 |
| Ambient temperature °C | 27.9 | 29.1 | 30 | 29.55 |
| Gross Efficiency (%) | | 85.5 | 85 | 85.3 |
| Net Efficiency (%) | | 90.8 | 90.3 | 90.6 |
| **Note:** | | | | |
| It was noted that the boiler No.1 was on the firing mode No.3 (High fire) with a steam pressure of 110 psi | | | | |
| The operating pressure range was noted as follows: | | | | |
| Cut in pressure(psi) | 100 | | | |
| cut out pressure (psi) | 120 | | | |

### 4.4.2 Boiler No.3 flue gas measurements

The flue gas measurements in respect of boiler No.3 are provided in Table 4.17, while Table 4.18 provides a summary of the boiler fuel consumption with respect to bed occupancy.

*Table 4-17– Boiler No.3 flue gas measurements*

| Flue gas analysis for Boiler No.3 | | | | |
|---|---|---|---|---|
| **Parameter measured** | **Sample 1** | **Sample2** | **sample 3** | **Average** |
| CO (ppm) | 1 | 1 | 1 | 1 |
| $CO_2$ (%) | 9.89 | 9.55 | 9.34 | 9.5 |
| $O_2$ (%) | 7.7 | 9.55 | 8.3 | 8.9 |

| | | | | |
|---|---|---|---|---|
| Flue gas Temperature °C | 82.7 | 130.9 | 162.8 | 146.9 |
| Ambient temperature °C | 27.7 | 29.5 | 29.9 | 29.7 |
| Gross efficiency (%) | | 88.1 | 86.2 | 87.2 |
| Net Efficiency (%) | | 93.6 | 91.6 | 92.6 |
| **Note;** | | | | |
| It was noted that the boiler No.3 was on the firing mode No.2 (Medium fire) at a steam pressure of 100psi. | | | | |
| The operating pressure range was noted as follows: | | | | |
| Cut in pressure(psi) | 100 | | | |
| cut out pressure(psi) | 120 | | | |
| **Note:** Boiler No. 2 was down for maintenance and is used as a standby unit. | | | | |

*Table 4-18 Data on Boiler fuel consumption and hospital occupancy*

| Period (2018) Month | No. of days | Hospital Occupancy | | Automotive gas oil (Diesel- AGO) Consumption | | | |
|---|---|---|---|---|---|---|---|
| | | % | IbD | intensity (litres/IbD) | Usage (Lts) | Equivalent (GJ) | GJ/IbD |
| Jan | 31 | 80% | 5580 | 5.5 | 34795.5 | 1,353 | 0.215 |
| Feb | 28 | 83% | 5229 | 5.3 | 33149.0 | 1,289 | 0.205 |
| March | 31 | 80% | 5580 | 5.8 | 38698.0 | 1,504 | 0.227 |
| April | 30 | 79% | 5333 | 5.7 | 35631.5 | 1,385 | 0.221 |
| May | 31 | 80% | 5580 | 6.0 | 39215.0 | 1,524 | 0.232 |
| June | 30 | 80% | 5400 | 5.3 | 35854.5 | 1,394 | 0.206 |
| July | 31 | 82% | 5720 | 6.4 | 39942.5 | 1,553 | 0.247 |
| Aug | 31 | 83% | 5789 | 5.7 | 38405.0 | 1,493 | 0.223 |
| Sept | 30 | 84% | 5670 | 6.2 | 39578.0 | 1,538 | 0.240 |
| Oct | 31 | 83% | 5789 | 5.2 | 32722.5 | 1,272 | 0.203 |
| Nov. | 30 | 84% | 5670 | 5.3 | 32478.0 | 1,262 | 0.206 |
| Dec. | 31 | 85% | 5929 | 5.1 | 31943.5 | 1,242 | 0.198 |
| Total | 365 | 983% | 67268 | **67.5** | **432,413** | **16,809** | **2.623** |
| **Average** | **30.4** | **82%** | **5,606** | **5.6** | **36034.4** | **1400.7** | **0.219** |

Boiler efficiency is important in the production of steam and consequently the generation of hot water as the higher the efficiency the lower the fuel consumption for a given heating load.

In this study the combustion efficiency of diesel (oil No.2) fired boilers was determined. Both gross and net combustion efficiencies were measured using a flue gas analyser. In determining combustion efficiency, only heat losses due to combustion are considered.

In determining Gross efficiency of a boiler it is assumed that the latent heat of vaporization in the exhaust vapour is lost to the atmosphere. On the other hand, net efficiency assumes that the latent heat in the exhaust vapour is recovered. Consequently, net efficiency is higher than the gross efficiency. However, in this study the latent heat of vaporization is not recovered and hence gross combustion efficiency is applicable.

In combustion processes, there is an optimum level of excess air for each type of burner or furnace design and fuel type. Only enough air should be supplied to ensure complete combustion of the fuel, since more than this amount increases the heat rejected to the stack, resulting in greater fuel consumption for a given process output and low boiler efficiency (Wayne C. Turner, 2007). A summary of the optimum excess air levels for various fuels is provided in Appendix A.1.

Boiler combustion efficiency can be improved by optimizing the percentage of oxygen in flue gas through adjustment of the speed of the forced draft fan preferably by using a variable speed drive. The efficiency may also be improved by rodding the fire tubes to remove any accumulated soot and descaling of the water side of the tubes. Efficiency may also be improved by using an air preheater for combustion air and an economiser to preheat feed water.

The use of fossil fuels in steam boilers results in emission of carbon dioxide, sulphur dioxide, sulphur trioxide and nitrous oxides which lead to environmental pollution and global warming (Woodruff Everett B., 2004). Consequently, it is advisable to monitor and minimize the emission of the pollutant gases from boilers so as to mitigate climate change.

## 4.5 Sizing of solar panels and specification of the integrated steam and solar water heating system

In chapter 3, the method to be used in determining the size and quantity of solar panels was presented. In this section the actual sizing of solar panels is explained.

### 4.5.1 Sizing of solar panels

In chapter 3, reference was made to the catalogue for "Dayliff Ultrasun UF flat plate solar water heaters" from Davies and Shirtliff. The specifications indicate that a solar panel (collector) with a collector area of $2.4m^2$ is adequate for seven (7) people. The same collector will give a maximum output of 14.3 kWh and a minimum output of 9.6 kWh or an average of 11.95kwh per day.

The water to be used in the solar collector should be appropriately treated to be clear and with TDS <600 mg/l and hardness <200mg/l ($CaCo_3$).

The maximum operating temperature is 150°C whereas the maximum operating pressure is 6 bar. The specifications for the solar water heater are given in table 4-19 and figure 4-4.

*Table 4-19 solar water heater performance data based on irradiation of $6kwh/m^2$ per day*

**SPECIFICATIONS**

| Model | | UFS 150D | UFS 200D | UFS 300D |
|---|---|---|---|---|
| System Tank Size (Litres) | | 150 | 200 | 300 |
| Typical Household (People) | | 5 | 7 | 10 |
| Flat Plate Collectors | | 1xFCP2.0 | 1xFCP2.4 | 2xFCP2.0 |
| Collector ($m^2$) | | 2 | 2.4 | 4 |
| Collector Weight (kgs) | | 32 | 38 | 64 |
| Collector Fluid Capacity (litres) | | 12 | 15 | 24 |
| Max Heat Output/Day (kWhrs) | | 11 | 14.3 | 22.3 |
| Min Heat Output/Day (kWhrs) | | 7.4 | 9.6 | 14.9 |
| Dimensions (mm) | A | 1000 | 1400 | 2100 |
| | B | 2000 | | |
| | C | 2600 | | |
| | D | 1170 | 1480 | 2300 |
| | E | 520 | | |
| | F | 620 | | |
| Empty Weight (kgs) | | 65 | 75 | 105 |
| Full Weight (kgs) | | 215 | 275 | 405 |

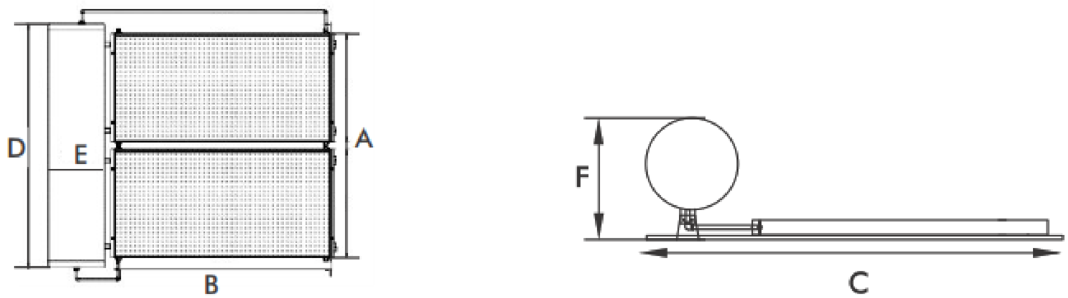



*Figure 4-4 solar collector dimensions (courtesy Davies & Shirtliff)*

The information is adequate to determine the size and number of solar panels for a given hot water demand. This is the method that was used in determining the size and quantity of solar panels in this study.

Tables 4-20 and 4-21 show the method used to determine the number of solar panels required to meet the hospital hot water demand. The following units of conversion have been used in the analysis below:

- 1 Liter of diesel is equal to 2.65 Kg $CO_2$
- 1 kWh is equal to 3.6 MJ.
- 1 US$ is equal to ksh 103.

*Table 4-20 -Assumptions in determination of Number of solar panels*

| **Assumptions:** | |
|---|---|
| Operating hours p.a | **8760** |
| Operating days p.a | **365** |
| Density of water(kg/m$^3$) | **1000** |
| Estimated Cost of diesel per litre | **86** |
| Calorific value of Diesel(kJ/litre) | **39000** |
| Specific heat capacity of water (kJ/kg-°C) | **4.19** |
| cost of solar panel (2m$^2$) | **80,000** |
| Lowest water temperature into solar collector | **15** |

| | |
|---|---|
| Average hot water supply temperature °C | **60** |
| Existing Boiler efficiency (average) | **0.85** |

*Table 4-21- Determination of Number of solar panels required in the installation*

| | | | | |
|---|---|---|---|---|
| **Existing Situation;** | | | | |
| Average water consumption per day ($m^3$) | **34.3** | | | |
| $Average\ water\ consumption\ per\ annum\ (m^3) = 34.3 \times 365$ | **12531.2** | | | |
| $Average\ energy\ consumption\ per\ day\ (Kj)$ $= 34.3 \times 1000 \times 4.19 \times (60 - 15)$ | **6,473,317.5** | | | |
| Average energy consumption per day (Mj) | **6,473.32** | | | |
| **Recommendation** | | | | |
| The design is to cater for 40% of the heating demand due to space limitations on the roof for mounting the solar collectors | **0.4** | | | |
| Install solar water heaters as detailed below: | | | | |
| Solar water heaters as "DAYLIFF Model UFS 200D - UltraSun premium" | | | | |
| collector area -2.4m² | **2.4** | | | |
| maximum heat output per day (kwh) | **14.30** | From catalogue | | |
| minimum heat output per day (kwh) | **9.60** | Savings are realizable if orientation of panels is optimized at a tilt angle of 16° towards the equator | | |
| Average heat output per day (kwh) | **11.95** | From catalogue | | |
| $Average\ heat\ output\ per\ day\ (Mj)$ $= 11.95 \times 3.6 = 43.02$ | **43.02** | | | |

| | | | | |
|---|---|---|---|---|
| $Recommended\ No\ of\ solar\ panels\ (collectors)\ to\ be\ mounted\ on\ the\ roof\ = average\ energy\ consumption\ per\ day / average\ heat\ output\ per\ solar\ collector\ per\ day$ $(6{,}473.32/\ 43.02) \times\ 0.4 = 60$ | **60** | | | |
| $Potential\ savings\ (kwh\ p.a) =\ 60\ \times\ 11.95\ \times\ 365 =\ 262{,}529$ | 262,529 | | | |
| Potential savings (GJ p.a) | 945 | | | |
| Estimated cost of investment (ksh)- solar panels | 4,815,113 | | | |
| Estimated cost of investment (ksh)- Materials & accessories | 662,935 | | | |
| Labour -15% of cost of equipment | 722,267 | 0.15 | | |
| Total Estimated cost of investment (ksh) | 6,200,315 | | | |
| Equivalent diesel savings: | | | | |
| Potential Heat savings (GJ p.a) | 945 | | | |
| $Equivalent\ fuel\ consumption\ per\ annum (litres) = (945\ \times\ 1{,}000{,}000)/\ (39{,}000\ \times 0.85) = 28{,}510$ | 28,510 | | | |
| $Potential\ savings\ (kg\ of\ CO2) =\ 28{,}510\ \times\ 2.65\ =\ 75{,}551.3$ | 75,551.3 | | | |
| $Potential\ savings\ (Tons\ of\ CO2) = \frac{75{,}551.3}{1000} =\ 75.55$ | 75.55 | | | |
| $Potential\ energy\ savings\ (ksh.p.a) =\ 28{,}510\ \times\ 85.86\ =\ 2{,}447{,}863$ | 2,447,863 | | | |
| Potential energy savings (USD. p.a) | 23,766 | | | |
| Simple payback period (years) | 2.53 | | | |

| | | | | |
|---|---|---|---|---|
| Required plan area ($m^2$) based on collector area | 144 | | | |

| | | | Length (m) | width (m) |
|---|---|---|---|---|
| Roof area required for the panels ($m^2$) based on external dimensions | 168 | | 30 | 5.6 |
| Add spacing between panels | 30 | | 30 | 1 |
| Total area required | 198 | | 30 | 6.6 |

The plan area required for the solar panel installation is 198 $m^2$ measuring 30m x 6.6 m.

### 4.5.2 Integrated boiler and solar system

The result of this study is an integrated system to use steam and solar energy to provide hot water for Hospital H1. In this study a determination and specification of the components of an integrated steam and solar water heating system has been carried out. Reference was made to technical brochures of solar collectors, calorifiers and other system components.

The proposed schematic of the integrated steam and solar water heating system is provided in Figure 4-14.

The integrated system consists of a diesel fired boiler which generates steam. The steam from the boiler is delivered to calorifiers for water heating, to steam hot pots in the kitchen for cooking and to the laundry dryer. Cold water is fed into the calorifiers by gravity from high level tanks. The steam transfers its enthalpy of evaporation to the cold water which is then heated to the required temperature of 60°C through the calorifier which is basically a heat exchanger. Hot water is continuously circulated between the calorifiers and the end uses by a pump. The end uses for hot water include the showers and wash hand basins in the wards, the kitchen sinks and the Laundry washing machines. The amount of steam delivered to the calorifiers is adjusted by a hot water temperature controller. A temperature sensor on the hot water return pipe from the end uses controls the size of opening in the controller and when the temperature is achieved the controller shuts off the supply of steam.

After giving up the enthalpy of evaporation, the steam changes phase from vapour into liquid (condensate) at high temperature. The condensate is then discharged from the calorifier through a steam trap into the condensate return pipe that delivers the condensate to the feed water tank. The condensate is then topped up with makeup water to cater for steam and condensate leaks.

The steam is admitted into the kitchen hot pots and the laundry dryer through gate valves and after discharge of enthalpy of evaporation, the resulting condensate is returned to the boiler feed water tank through steam traps and steel piping. The gate valves are closed whenever the hot pots and the laundry dryer are not in use.

The system also contains 60 solar collectors (panels) arranged in 4 rows of 15 collectors each. Cold water that is mixed with 50% glycol is continuously circulated by a pump between the solar collectors and hot water storage tanks which have heat exchangers. Cold water is fed by gravity into the hot water storage tanks and then taken through the steam heated calorifiers for boosting the hot water temperature to 60°C. If the temperature of the water from the storage tanks is high enough especially during sunny days, then steam is not allowed into the calorifier. However, based on demand and especially during the cold season and at night steam is used to achieve the desired hot water temperature.

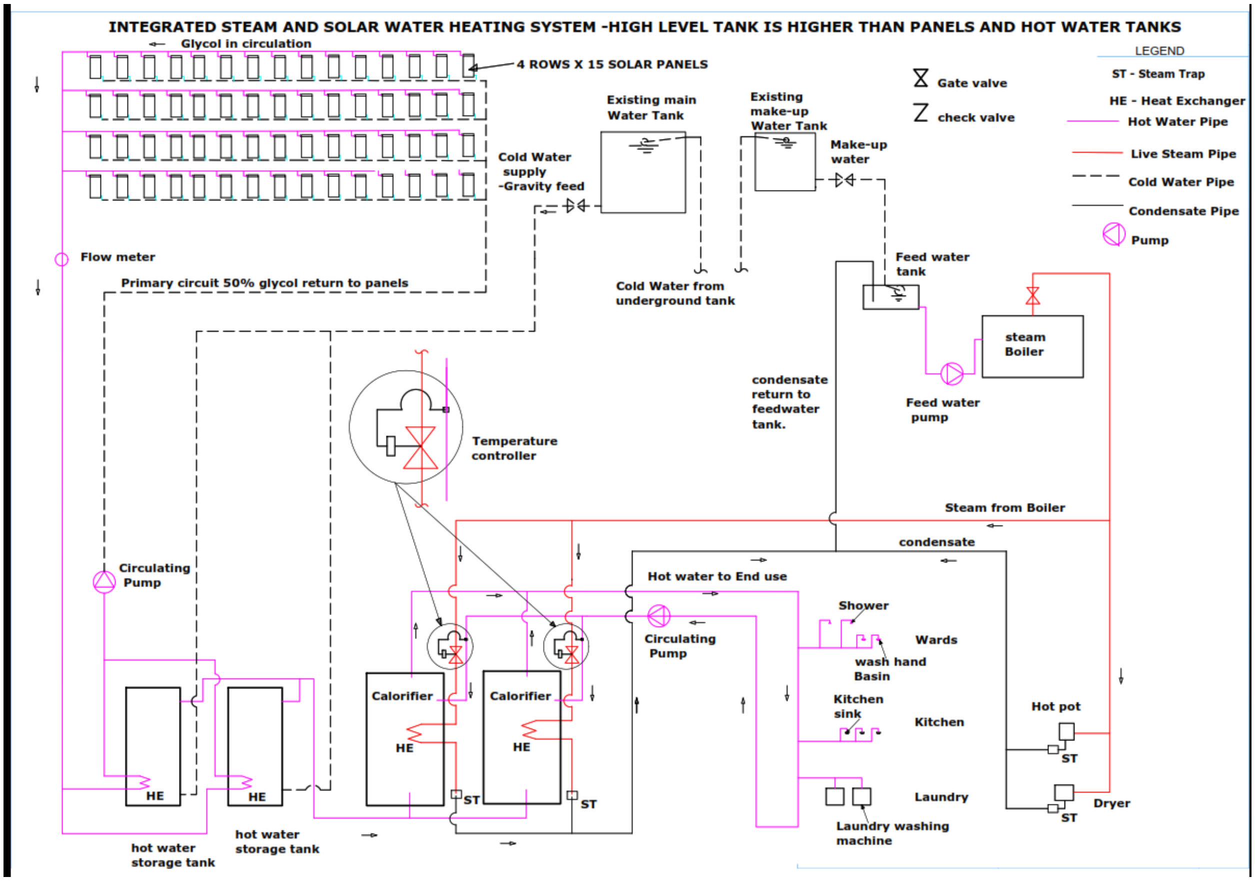



*Figure 4-5 schematic of the proposed installation of the integrated solar and steam system at Hospital H1.*

Schedule of system components is given in the bill of quantities in Table A9-1 in Appendix 9.

## 4.6 Economic evaluation of the existing boiler hot water generation system and the integrated system

An economic evaluation of the integrated system was carried out including life cycle cost analysis. A suitable discounting factor reflecting the commercial lending rates was used to do the analysis. Various project viability indicators were determined including: simple payback period (years), return on investment (ROI), net present value (NPV) and internal rate of return (IRR) (Paneerselvam R., 2001) . The definitions of the financial indicators are given as follows:

$$Simple\ payback\ period\ (SPBP) in\ years\ =\ the\ investment\ cost\ /\ net\ annual\ savings$$

$$The\ return\ on\ investment\ (ROI) is\ given\ as\ a\ percentage$$

$$= \left(\frac{Net\ annualsavings}{investment\ cost}\right) \times\ 100$$

$$Present\ value\ (P) of\ a\ future\ cashflow\ (F) = \frac{Future\ value(F)}{(1 +\ I)^{n}}$$

$$Future\ value\ (F)\ of\ a\ present\ value\ (P)\ =\ Present\ value\ (P)\ x\ (1\ + I)^{n}$$

Net present value (NPV) is the sum of all positive cash flows (savings) and negative cash flows (expenses) discounted to present value. The negative cash flows include the initial investment cost. A project is feasible if NPV is positive.

$$Thus\ NPV\ \ =\ Discounted\ sum\ of\ positive\ cashflows\ +\ Discounted\ sum\ of\ negative\ cashflows$$

Internal rate of return (IRR) is the discount factor that gives a net present value of Zero.

$$This\ implies\ a\ discount\ factor\ that\ is\ applicable\ when\ cash\ inflows\ =\ cash\ outflows$$

Where:

I = the discount factor

n = No. of years from present (Normally equal to the economic or useful life of a project)

NPV and IRR can be obtained by using the interest compounding tables or Microsoft Excel.

The assumptions in this economic evaluation are as follows:

- US$ = Ksh 103
- Economic life of the project is equal to the amortization period of 10 years
- Bank loan interest rate is 12%
- Discount factor is 15%
- Investment cost (Ksh) obtained from the bill of quantities in Table 4-25 , is Ksh 6,200,315 (US$ 60,197)

- Net Annual savings, A, (Ksh) is 2,447,863 ( US $ 23,766)

Analysis:

$$Simple\ payback\ period\ (SPBP) - \ (years) = \frac{60{,}197}{23{,}766} \ = \ 2.53$$

$$Return\ on\ investment\ (ROI)\% \ = \ \left(\frac{1}{SPBP}\right) X100 \ = \ \left(\frac{1}{2.5}\right) X100 \ = \ 39.5$$

The formula to determine present value is given as follows:

$$Present\ value\ of\ annual\ savings\ (PV) = \ A\ X\ \left(\frac{P}{A}, 15\%, 10\right)$$

i.e present value (PV) sum given annual savings (A) and P/A at a discount factor (minimum acceptable rate of return) of 15% , and a project life of 10 years.

(Reference to compound interest table in Appendix A8-1 for 15% gives a present worth factor P/A = 5.019)

$$Hence\ Present\ Value\ (PV) in\ \ (US\$) = \ 23{,}766\ x\ 5.019 \ = \ US\$\ \ 119{,}280$$

$$Net\ present\ value\ (NPV) = \ \ Net\ annual\ savings - \ investment\ cost$$

$$= \ US\$\ (119{,}280 \ - 60{,}197) = \ 59{,}083$$

The net present value is positive thus indicating that the project is economically viable

Internal rate of return (IRR):

To find IRR set investment cost = PV of net cash flow

Investment cost = A X (P/A, i, 10)

Hence investment cost / Net annual savings = (P/A, i, 10) = 60,197/23,766 = 2.53

Next, Find a percentage (%) that has a value of 2.53 at 10 years from the compound interest tables (Wayne C. Turner, 2007).

35% corresponds to a factor of 2.715 whereas 40% corresponds to 2.414. Hence, IRR is approximately 40%.

Since the value is more than the discounting factor of 15%, the project is feasible.

# Chapter 5 Conclusions and recommendations

## 5.1 Introduction

This chapter presents the conclusions and recommendations arising from the results of the study. These are aligned with the objectives of the study including hot water demand, energy and cost of producing hot water, boiler efficiency in hospital H1, size and quantity of solar panels and economic evaluation of the integrated system.

## 5.2 Conclusions

A review was made of the bed occupancy, water, electricity and fuel consumption records of the hospitals. In addition, actual water flow measurements were conducted at Hospital H1 using an ultrasonic flow meter. The analysis from historical records showed the following:

The lowest and highest average hot water usage intensity in each month during the year 2018 were 180 and 194 litres per inpatient bed day respectively based on historical data. The actual measurements at Hospital H1 established a hot water usage intensity of 181.7 litres per inpatient bed day which was within the range for historical data and hence acceptable.

It was established that in Hospital H1 the total usage of AGO in 2018 amounted to 432,413 litres equivalent to 16,809 GJ. The fuel energy intensity for water heating only was 0.0412 GJ/ Inpatient bed-day.

Hospital H3 uses only electrical energy for all its activities. Total usage of electrical energy for the hospital in 2018 amounted to 1,413,311 kWh (5,088 GJ) with an average of 117,776 kWh (424 GJ) per month. The results showed that the energy intensity for water heating was 0.0443GJ/ inpatient bed day.

Hospital H2 uses both electrical and thermal energy. The total usage of HFO in 2018 amounted to 209,450 litres equivalent to 8,738 GJ

The results indicate that the comparative usage of energy for water heating by the hospitals in GJ/inpatient bed day is 0.0412 and 0.0443 for Hospital H1 using AGO and hospital H3 using electricity respectively. The cost of thermal energy was US$ 0.88 and

US$2.14 per inpatient bed day for Hospital H1 and hospital H3 respectively. No records were available on the usage of energy for water heating alone in hospital H2.

The measurements confirmed that flue gas temperature °C, oxygen ($O_2$) percentage in flue gas and gross efficiency (%) of boiler No.1 were 195.9; 6.8 ; and 85.3% respectively.

The measurements confirmed that flue gas temperature °C, oxygen ($O_2$) percentage in flue gas and gross efficiency (%) of boiler No.3 were 146.9; 8.9 ; and 87.2% respectively.

The recommended oxygen levels in flue gas are given in Table A1-1 in Appendix A-1. The recommended value for oil No.2 (AGO) is 3 to 4 % oxygen in flue gas. The measurements indicate that the oxygen levels were excessive at 6.8% and 8.9% for boiler no. 1 and 3 respectively.

The size and quantity of solar panels required to meet the heating demand has been determined and specified along with other components of the integrated steam and solar water heating system and the related bill of quantities is in Appendix A9. The solar panels proposed for installation are as "DAYLIFF Model UFS 200D - UltraSun premium" with collector area of 2.4m$^2$.

The economic evaluation of the proposed integrated steam and solar water heating system was carried out and the results are summarized as follows: Discount factor; 15%; Projected Investment cost (Ksh); 6,200,315; Projected Investment cost (US$); 60,197; Projected Net Annual savings (A)-(Ksh); 2,447,863; Projected Net Annual savings (A)-(US$); 23,766; Simple payback period (SPBP) in years;2.53; Return on investment (ROI)%;39.5; Net present value (NPV)-(US$); 59,083 and Internal rate of return (IRR) of 40%.

The Research has shown that it is economically feasible to install an integrated solar and steam system for domestic water heating in hospitals.

## 5.3 Recommendations

The first recommendation is for Hospital H1 to adjust the Forced draft fans and the air to fuel ratio mechanism to obtain the required amount of oxygen in the flue gas in order to optimize boiler combustion efficiency.

The second recommendation is for the hospitals that are currently using fossil fuel fired boilers as a source of generating hot water to install solar water heaters and integrate with the existing systems.

Recommendations for further study are as follows:

i) Evaluation of performance of sun tracking solar collectors and integration with boilers for steam generation

ii) A comparison of performance between flat plate and evacuated tube collectors in water heating

**References**


Denholm P. (March 2007). *Technical report NREL/TP-640-41157.* National Renewable Energy Laboratory (NREL) - USA Department of energy.

Daniel Sanchez Herranz. (2009, June). Design of a solar water heating system in a residential building, Msc. Thesis , University of Gavle.

Duffie J.A, B. W. (1991). *Solar Engineering of thermal processes.* Wisconsin: University of Wisconsin.

Government printer, Kenya,. (2009). Quality standards for Kenya Essential package of health , 2009 Edition. Nairobi.

GUIDE, C. (n.d.). CIBSE Guide G; Public health Engineering, 2004 Edition.

Hassan AL-Hasnawi. (2015). Solar heat in industrial processes, integration of parabolic trough solar collectors in Dairy plants and pharmaceutical plants, UMEA University.

Hortelano, A. G. (2011, April). Water heating system - Application in an apartment building, Msc. Thesis, Tampere University of Technology.

Kalogirou, S. A. (2013). *Solar Energy Engineering processes and systems, 2nd Edition, Cyprus University of Technology.* Limassol, Cyprus: Academic press.

Kebede, D. (2016, June). Design and analysis of solar thermal system for hot water supply to Minilik hospital new building, Msc. Thesis, Addis Ababa University institute of Technoclogy.

Lang, S. (2010, December). Boiler Control - improving efficiency of boiler systems, Msc. Thesis, Lund University. Lund University.

McNulty, J. C. (2013). Domestic hot water efficiency and losses, Msc. Thesis, University of Strathclyde. Orkney.

Monitoring and modelling hot water consumption in hotels for solar thermal water heating system optimization, Msc. Thesis , Appalachian State University. (2011, May).

NASA. (n.d.). *NASA Solar irradiance*. Retrieved from NASA.

(2001). *OECD Health data, 2001.* OECD.

Paneerselvam R. (2001). Paneerselvam R. Engineering Economics, PHI Learning Private Limited, New Delhi, 2001. New Delhi: PHI Learning private Limited.

printer, Kenya Government. (2012). The Energy (Solar water heating) regulations 2012, Kenya. Nairobi.

Study, H. (2018). *Study Hospital energy and occupancy data file.*

The institute of plumbing, U. (2002 Edition). Plumbing Engineering services design guide, 2002 Edition.

Wayne C. Turner, S. D. (2007). *Energy management handbook, 6th Edition, Oklahoma state University.* Oklahoma: The Fairmont Press Inc,.

Woodruff Everett B., L. H. (2004). *Steam plant operation, 8th Edition.* Montreal: McGraw-Hill.

# Appendices

## A. 1: Appendix- Boiler performance data

*Table A1-1 Typical excess air requirements for various fuels used in boilers (Wayne C. Turner, 2007)*

| Fuel Type | Firing Method | Optimum Excess Air (%) | Equivalent $O_2$ (by Volume) |
|---|---|---|---|
| Natural gas | Natural draft | 20-30 | 4-5 |
| Natural gas | Forced draft | 5-10 | 1-2 |
| Natural gas | Low excess air | .04-0.2 | 0.1-0.5 |
| Propane | — | 5-10 | 1-2 |
| Coke oven gas | — | 5-10 | 1-2 |
| No. 2 oil | Rotary cup | 15-20 | 3-4 |
| No. 2 oil | Air-atomized | 10-15 | 2-3 |
| No. 2 oil | Steam-atomized | 10-15 | 2-3 |
| No. 6 oil | Steam-atomized | 10-15 | 2-3 |
| Coal | Pulverized | 15-20 | 3-3.5 |
| Coal | Stoker | 20-30 | 3.5-5 |
| Coal | Cyclone | 7-15 | 1.5-3 |

[a]To maintain safe unit output conditions, excess-air requirements may be greater than the optimum levels indicated. This condition may arise when operating loads are substantially less than the design rating. Where possible, check vendors' predicted performance curves. If unavailable, reduce excess-air operation to minimum levels consistent with satisfactory output.

## A.2: Appendix –Solar energy collector types & operating temperatures

*Table A2-1 Solar energy collector types and operating temperatures [2]*

| Motion | Collector type | Absorber type | Concentration ratio | Indicative temperature range (°C) |
|---|---|---|---|---|
| Stationary | Flat-plate collector (FPC) | Flat | 1 | 30–80 |
| | Evacuated tube collector (ETC) | Flat | 1 | 50–200 |
| | Compound parabolic collector (CPC) | Tubular | 1–5 | 60–240 |
| Single-axis tracking | | | 5–15 | 60–300 |
| | Linear Fresnel reflector (LFR) | Tubular | 10–40 | 60–250 |
| | Cylindrical trough collector (CTC) | Tubular | 15–50 | 60–300 |
| | Parabolic trough collector (PTC) | Tubular | 10–85 | 60–400 |
| Two-axis tracking | Parabolic dish reflector (PDR) | Point | 600–2000 | 100–1500 |
| | Heliostat field collector (HFC) | Point | 300–1500 | 150–2000 |

*Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.*

**A3: Appendix –Solar Collector efficiency**

**A3-1: Solar collector Efficiency:**

A comparison of the efficiency of various collectors at irradiance levels of 500 W/m² and 1000 W/m² is shown in the figure A3-1( Kalogirou, 2013). Five representative collector types are considered as follows:

- Flat-plate collector (FPC).
- Advanced flat-plate collector (AFP). In this collector, the risers are ultra-sonically welded to the absorbing plate, which is also electroplated with chromium selective coating.
- Stationary compound parabolic collector (CPC) oriented with its long axis in the east-west direction.
- Evacuated tube collector (ETC).
- Parabolic trough collector (PTC) with E-W tracking.

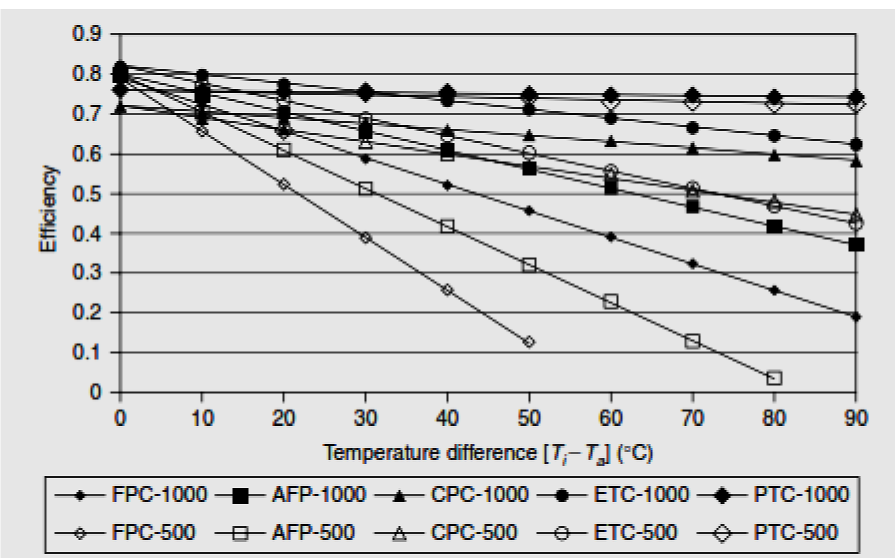



*Figure A3-1 shows the efficiency of various solar collectors as a function of temperature of ambient air ($T_a$) and incoming water ($T_i$) (Kalogirou, 2013)*

**A4: Appendix –Hot water requirements and a typical configuration of calorifier**

Table A4 -1 shows total (cold and hot) water demand for various buildings on the left and hot water demand on the right (The institute of plumbing – 2002 edition)

| Type of Building | Litres | Criteria/Unit |
|---|---|---|
| Dwellings | | |
| - 1 bedroom | 210 | Bedroom |
| - 2 bedroom | 130 | Bedroom |
| - 3+ bedrooms | 100 | Bedroom |
| - Student en-suite | 100 | Bedroom |
| - Student, communal | 90 | Bed space |
| - Nurses Home | 120 | Bed space |
| - Children's Home | 135 | Bed space |
| - Elderly sheltered | 120 | Bedroom |
| - Elderly Care Home | 135 | Bed space |
| - Prison | 150 | Inmate |
| Hotels | | |
| - Budget | 135 | Bedroom |
| - Travel Inn/Lodge | 150av | Bedroom |
| - 4/5 Star Luxury | 200 | Bedroom |
| Offices & general work places | | |
| - with canteen | 45 | Person (1) |
| - without canteen | 40 | Person (1) |
| Shops | | |
| with canteen | 45 | Person |
| - without canteen | 40 | Person |
| Factory | | |
| - with canteen | 45 | Person |
| - without canteen | 40 | Person |
| Schools | | |
| - Nursery | 15 | Pupil |
| - Primary | 15 | Pupil |
| - Secondary | 20 | Pupil |
| - 6th Form College | 20 | Pupil |
| - Boarding | 90 | Pupil |
| Hospitals | | |
| - District General | 600 | Bed |
| - Surgical ward | 250 | Bed |
| - Medical ward | 220 | Bed |
| - Paediatric ward | 300 | Bed |
| - Geriatric ward | 140 | Bed |
| Sports Changing | | |
| - Sports Hall | 35 | Person |
| - Swimming Pool | 20 | Person |
| - Field Sports | 35 | Person |
| - All weather pitch | 35 | Person |
| Places of Assembly (excl. staff) | | |
| - Art Gallery | 6 | Person |
| - Library | 6 | Person |
| - Museum | 6 | Person |
| - Theatre | 3 | Person |
| - Cinema | 3 | Person |
| - Bars | 4 | Person |
| - Night Club (3) | 4 | Person |
| - Restaurant | 7 | Cover |

| Type of building | Daily (litres) | Stored (litres) | Unit |
|---|---|---|---|
| Dwellings | | | |
| - 1 bedroom | 115 | 115 | Bedroom |
| - 2 bedroom | 75 | 115 | Bedroom |
| - 3 + bedrooms | 55 | 115 | Bedroom |
| - Student en-suite | 70 | 20 | Bedroom |
| - Student, comm | 70 | 20 | Bedspce |
| - Nurses home | 70 | 20 | Bedspce |
| - Children's home | 70 | 25 | Bedspce |
| - Elderly sheltered | 70 | 25 | Bedroom |
| - Elderly care home | 90 | 25 | Bedspace |
| - Prison | | | Inmate |
| Hotels | | | |
| - Budget | 115 | 35 | Bedroom |
| - Travel Inn/Lodge | 115 | 35 | Bedroom |
| - 4/5 Star Luxury | 135 | 45 | Bedroom |
| Offices & general work places | | | |
| - with canteen | 15 | 5 | Person |
| - without canteen | 10 | 5 | Person |
| Shops | | | |
| - with canteen | 15 | 5 | Person |
| - without canteen | 10 | 5 | Person |
| Factory | | | |
| - with canteen | 15 | 5 | Person |
| - without canteen | 10 | 5 | Person |
| Schools | | | |
| - Nursery | 15 | 5 | Pupil |
| - Primary | 15 | 5 | Pupill |
| - Secondary | 15 | 5 | Pupil |
| - 6th form college | 15 | 5 | Pupil |
| - Boarding | 114 | 25 | Pupil |
| Hospitals | | | |
| - District General | 200 | 50 | Bed |
| - Surgical ward | 110 | 50 | Bed |
| - Medical ward | 110 | 50 | Bed |
| - Paediatric ward | 125 | 70 | Bed |
| - Geriatric ward | 70 | 40 | Bed |
| Sports changing | | | |
| - Sports Hall | 20 | 20 | Person |
| - Swimming Pool | 20 | 20 | Person |
| - Field Sports | 35 | 35 | Person |
| - All weather pitch | 35 | 35 | Person |
| Places of assembly (excl. staff) | | | |
| - Art Gallery | 2 | 1 | Person |
| - Library | 2 | 1 | Person |
| - Museum | 1 | 1 | Person |
| - Theatre | 1 | 1 | Person |
| - Cinema | 1 | 1 | Person |
| - Bars | 2 | 1 | Person |
| - Night Club | 1 | 1 | Person |
| - Restaurant | 6 | 6 | Cover |

## A4-2: A typical configuration of a calorifier and a solar tank

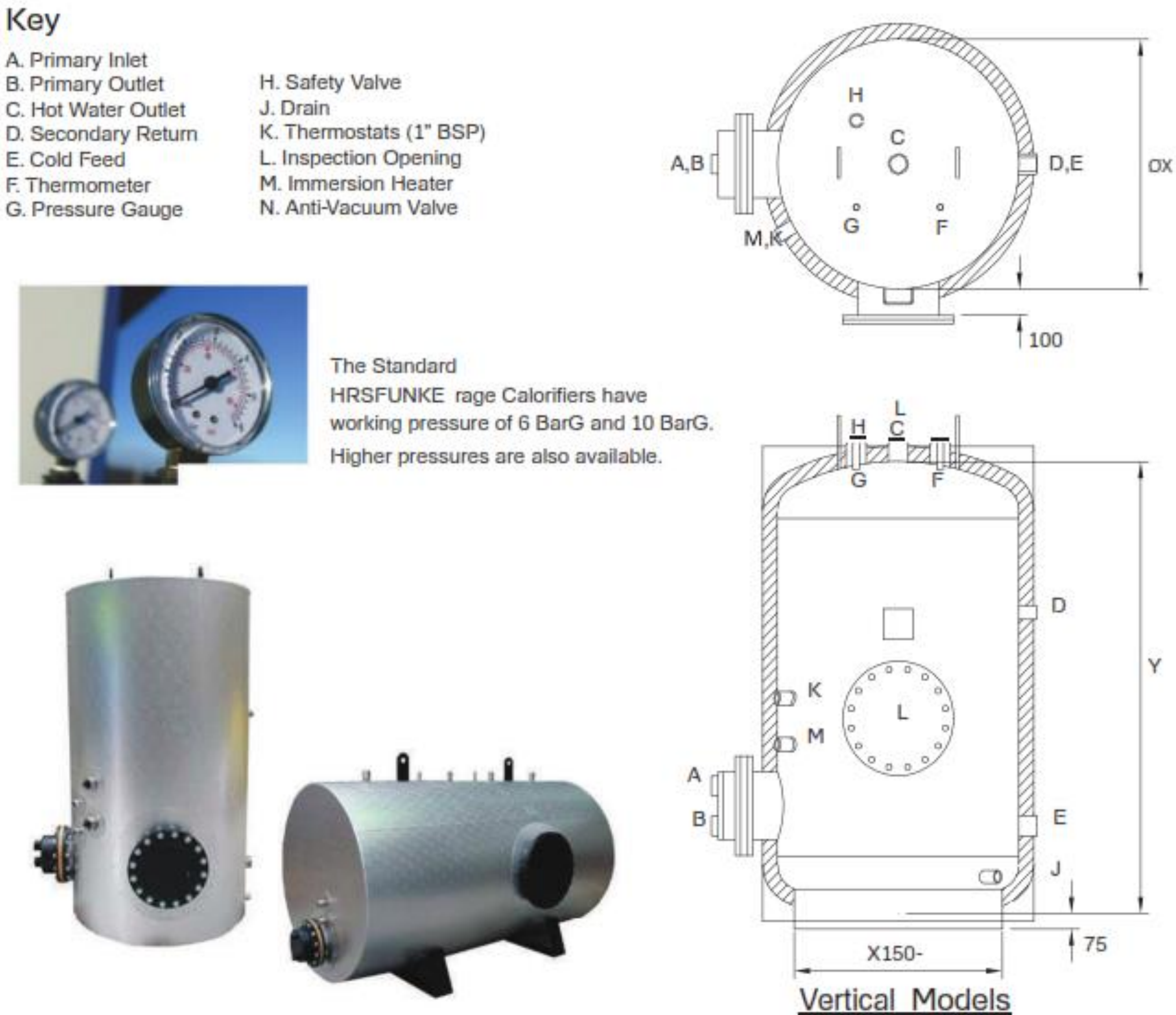
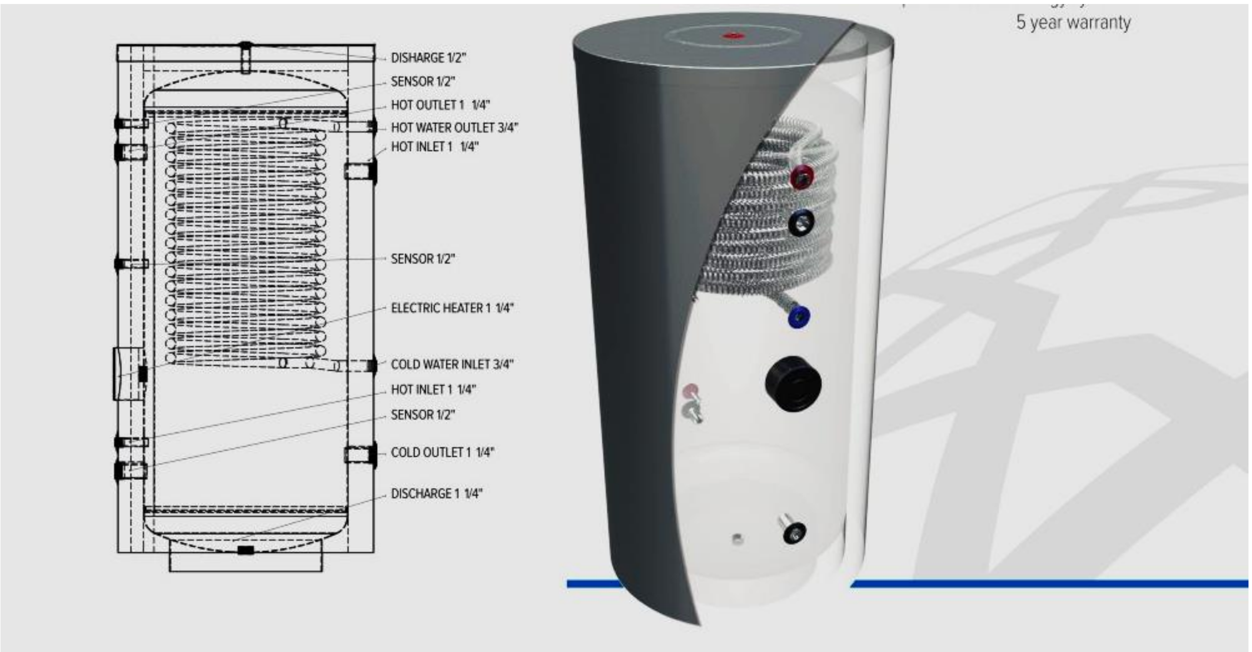



*Figure A4-2 Source: Manufacturer's catalogue on HRSFUNKE storage calorifiers*




## TECHNICAL SPECIFICATIONS

| | SOLITANK 200 | SOLITANK 300 | SOLITANK 500 | SOLITANK 1000 |
|---|---|---|---|---|
| Product Code | MA-0001 | MA-0002 | MA- 0492 | Ma- 0493 |
| Height (mm) | 1245 | 1770 | 1653 | 2033 |
| Diameter (mm) | 542 | 542 | 750/807 | 1017 |
| Net Weight (kg) | 75 | 85 | 100 | 190 |
| Volume (lt) | 170 | 245 | 454 | 970 |
| Insulation | 50 mm /40 kg/m$^3$ | 50 mm /40 kg/m$^3$ | 50 mm /40 kg/m$^3$ 80 mm /18 kg/m$^3$ | 80 mm /18 kg/m$^3$ |
| Insulating Material | Polyurethane (CFC Free) | Polyurethane (CFC Free) | Polyurethane / 18 Density Foam Rubber (CFC Free) | 18 Density Foam Rubber |
| Outer Cylinder Materials | Electrostatic Powder Painted ST 37 Steel | Electrostatic Powder Painted ST 37 Steel | Electrostatic Powder Painted ST 37 Steel / Leatherette Jacket | Leatherette Jacket |
| Materials of Coil | AISI 316 L Stainless Steel | AISI 316 L Stainless Steel | AISI 316 L Stainless Steel | AISI 316 L Stainless Steel |
| Number of Coils | 1 | 1 | 1 | 1 |
| 1. Coil Area ( m$^2$ ) | 3,83 | 3,83 | 5,48 | 8,76 |

*Figure A4-3 shows specifications for hot water storage tank with heat exchangers*

**A5: Appendix – Typical solar collector installation schematic**

The schematic below shows a typical installation of solar water heaters with forced circulation of the heat transfer medium.

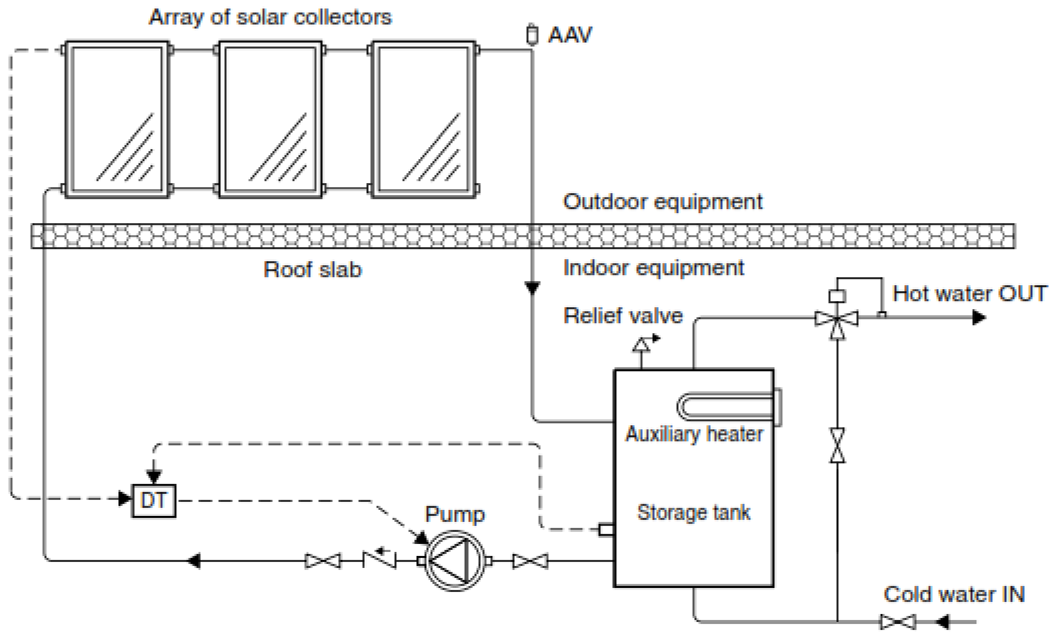



*Figure A5-1 typical installation of a solar water heating system with forced circulation (Kalogirou, 2013)*

**A6: Appendix –Solar radiation & weather data**

The solar radiation data from the NASA website is given in Table A6-1 below:

**A 6-1 Solar radiation data**

*Table A6-1 solar radiation data –parameters for tilted solar panels (NASA Solar irradiance, n.d.)*

***Parameters for Tilted Solar Panels:***

**Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface ($kWh/m^2/day$)**

| Lat 1.292 Lon 36.822 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SSE HRZ | 6.49 | 6.98 | 6.68 | 6.20 | 6.20 | 5.94 | 5.89 | 6.26 | 6.90 | 6.29 | 5.65 | 6.05 | 6.28 |
| K | 0.65 | 0.67 | 0.63 | 0.60 | 0.63 | 0.62 | 0.61 | 0.62 | 0.66 | 0.61 | 0.56 | 0.62 | 0.62 |
| Diffuse | 1.59 | 1.62 | 1.91 | 1.94 | 1.68 | 1.62 | 1.70 | 1.78 | 1.75 | 1.92 | 1.93 | 1.67 | 1.76 |
| Direct | 7.47 | 7.81 | 6.75 | 6.07 | 6.69 | 6.57 | 6.30 | 6.47 | 7.28 | 6.29 | 5.59 | 6.78 | 6.67 |
| Tilt 0 | 6.41 | 6.89 | 6.59 | 6.12 | 6.12 | 5.86 | 5.81 | 6.18 | 6.81 | 6.21 | 5.58 | 5.98 | 6.21 |
| Tilt 1 | 6.46 | 6.92 | 6.60 | 6.13 | 6.14 | 5.89 | 5.84 | 6.19 | 6.81 | 6.23 | 5.61 | 6.02 | 6.23 |
| Tilt 16 | 6.95 | 7.18 | 6.51 | 6.13 | 6.36 | 6.19 | 6.09 | 6.28 | 6.64 | 6.33 | 5.92 | 6.53 | 6.42 |
| Tilt 90 | 4.09 | 3.29 | 1.98 | 2.24 | 2.98 | 3.29 | 3.07 | 2.55 | 1.68 | 2.66 | 3.32 | 4.06 | 2.94 |
| OPT | 7.08 | 7.18 | 6.61 | 6.17 | 6.36 | 6.22 | 6.10 | 6.29 | 6.81 | 6.34 | 5.96 | 6.68 | 6.48 |
| OPT ANG | 28.0 | 18.0 | 4.00 | 8.00 | 18.0 | 22.0 | 20.0 | 13.0 | 1.00 | 13.0 | 24.0 | 30.0 | 16.6 |

*Table A6-2 Parameters for sizing and pointing of solar panels (NASA Solar irradiance, n.d.)*

***Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:***

**Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times ($kW/m^2$)**

| Lat -1.262 Lon 36.824 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average@00 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Average@03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| Average@06 | 0.45 | 0.46 | 0.46 | 0.42 | 0.38 | 0.35 | 0.34 | 0.37 | 0.47 | 0.50 | 0.45 | 0.47 |
| Average@09 | 0.86 | 0.92 | 0.89 | 0.77 | 0.71 | 0.67 | 0.69 | 0.73 | 0.87 | 0.83 | 0.75 | 0.81 |
| Average@12 | 0.63 | 0.69 | 0.66 | 0.59 | 0.56 | 0.54 | 0.56 | 0.57 | 0.62 | 0.56 | 0.52 | 0.56 |
| Average@15 | 0.12 | 0.14 | 0.12 | 0.09 | 0.07 | 0.08 | 0.09 | 0.10 | 0.08 | 0.06 | 0.06 | 0.09 |
| Average@18 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Average@21 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

### A-6.2 Nairobi county Annual temperature profile

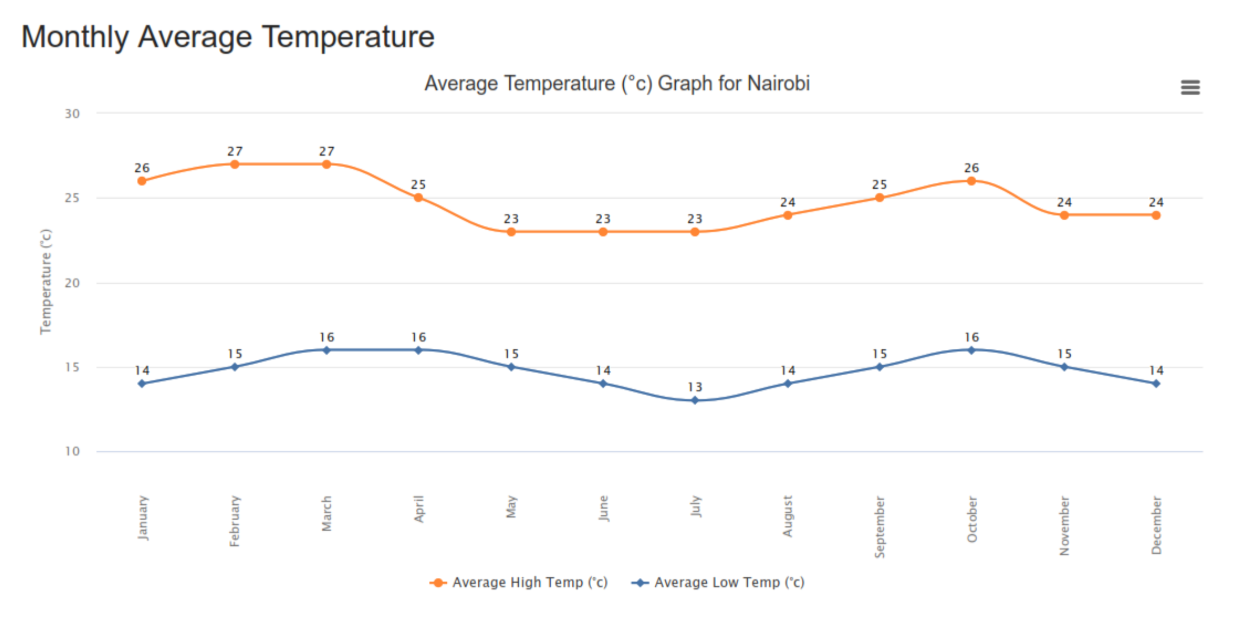
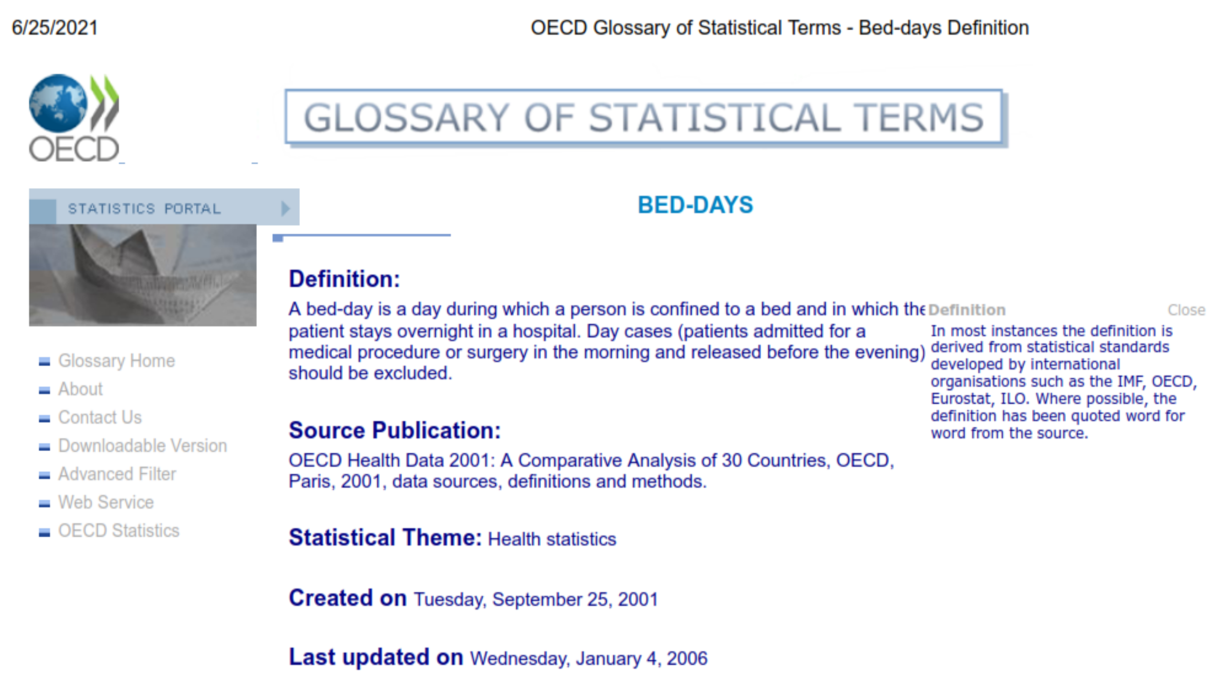



*Figure A 6-1- Nairobi county annual temperature profile -courtesy www.worldweatheronline.com*

## A7: OECD health data



6/25/2021 OECD Glossary of Statistical Terms - Bed-days Definition

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**BED-DAYS**

**Definition:**

A bed-day is a day during which a person is confined to a bed and in which the patient stays overnight in a hospital. Day cases (patients admitted for a medical procedure or surgery in the morning and released before the evening) should be excluded.

Definition Close

In most instances the definition is derived from statistical standards developed by international organisations such as the IMF, OECD, Eurostat, ILO. Where possible, the definition has been quoted word for word from the source.

**Source Publication:**

OECD Health Data 2001: A Comparative Analysis of 30 Countries, OECD, Paris, 2001, data sources, definitions and methods.

**Statistical Theme:** Health statistics

**Created on** Tuesday, September 25, 2001

**Last updated on** Wednesday, January 4, 2006

**A8: Primary data**

*Table A8-1: water flow measurements at hospital H1*

| Time (Hrs) | Flow Rate (M³/H) | Cumulative Flow( M³) | Net Consumption (M³) |
|---|---|---|---|
| 5pm | 1.63899 | 59.8022 | |
| 6pm | 1.48593 | 61.4065 | 1.6043 |
| 7pm | 0.98255 | 63.0775 | 1.671 |
| 8pm | 1.76622 | 64.6372 | 1.5597 |
| 9pm | 1.67756 | 66.1802 | 1.543 |
| 10pm | 1.46443 | 67.834 | 1.6538 |
| 11pm | 1.02808 | 69.2969 | 1.4629 |
| 12 midnight | 1.46688 | 0.6437 | 0.6437 |
| 1am | 1.19933 | 1.945 | 1.3013 |
| 2am | 1.09013 | 2.9436 | 0.9986 |
| 3am | 0.68707 | 3.7706 | 0.827 |
| 4am | 1.34629 | 4.8067 | 1.0361 |
| 5am | 1.67096 | 5.9789 | 1.1722 |
| 6am | 2.18444 | 7.87775 | 1.89885 |
| 7am | 2.73519 | 9.90897 | 2.03122 |
| 8am | 1.8739 | 12.1841 | 2.27513 |
| 9am | 2.32927 | 14.6909 | 2.5068 |
| 10am | 2.35638 | 16.824 | 2.1331 |
| 11am | 1.2754 | 18.8812 | 2.0572 |
| 12 noon | 1.29713 | 20.3663 | 1.4851 |
| 1pm | 2.23168 | 22.1474 | 1.7811 |
| 2pm | 1.90813 | 23.9933 | 1.8459 |
| 3pm | 1.50408 | 25.9973 | 2.004 |
| 4pm | 1.94097 | 27.9232 | 1.9259 |
| | | | 37.4179 |
| 5pm | 1.23907 | 28.1123 | 0.1891 |
| 6pm | 2.71621 | 31.1472 | 3.0349 |
| 7pm | 2.48249 | 33.6943 | 2.5471 |
| 8pm | 2.03697 | 34.3249 | 0.6306 |
| 9pm | 1.55468 | 36.2697 | 1.9448 |
| 10pm | 1.92176 | 38.4231 | 2.1534 |
| 11pm | 1.81623 | 39.2456 | 0.8225 |
| 12 midnight | 1.14769 | 0.2145 | 0.2145 |
| 1am | 1.1907 | 0.2328 | 0.0183 |
| 2am | 3.01054 | 1.2114 | 0.9786 |
| 3am | 1.49878 | 2.5679 | 1.3565 |

| | | | |
|---|---|---|---|
| 4am | 1.94945 | 3.6412 | 1.0733 |
| 5am | 1.23924 | 4.1317 | 0.4905 |
| 6am | 1.12316 | 4.5254 | 0.3937 |
| 7am | 0.93516 | 5.6173 | 1.0919 |
| 8am | 2.2965 | 10.4633 | 4.846 |
| 9am | 1.1354 | 11.2643 | 0.801 |
| 10am | 1.45938 | 13.4314 | 2.1671 |
| 11am | 2.27772 | 14.1311 | 0.6997 |
| 12 Noon | 1.24436 | 15.1714 | 1.0403 |
| 1pm | 2.47332 | 17.2148 | 2.0434 |
| 2pm | 2.46357 | 19.2319 | 2.0171 |
| 3pm | 1.26844 | 21.9561 | 2.7242 |
| | | | 33.2785 |
| 4pm | 1.13049 | 22.8411 | 0.885 |
| 5pm | 2.18367 | 24.5239 | 1.6828 |
| 6pm | 1.83636 | 26.3155 | 1.7916 |
| 7pm | 1.21159 | 27.6495 | 1.334 |
| 8pm | 0.927035 | 29.0437 | 1.3942 |
| 9pm | 1.17944 | 30.201 | 1.1573 |
| 10pm | 1.43885 | 31.7104 | 1.5094 |
| 11pm | 0.962103 | 33.4979 | 1.7875 |
| 12mid night | 1.3266 | 34.9938 | 1.4959 |
| 1am | 1.45815 | 0 | 0 |
| 2am | 1.96095 | 1.32653 | 1.32653 |
| 3am | 1.24889 | 2.54516 | 1.21863 |
| 4am | 0.421182 | 3.58651 | 1.04135 |
| 5am | 0.533671 | 4.1066 | 0.52009 |
| 6am | 0.666124 | 4.91842 | 0.81182 |
| 7am | 0.981918 | 6.02869 | 1.11027 |
| 8am | 1.25907 | 7.69711 | 1.66842 |
| 9am | 2.21621 | 9.75519 | 2.05808 |
| 10am | 2.18249 | 12.1333 | 2.37811 |
| 11am | 2.04497 | 14.3137 | 2.1804 |
| 12pm | 1.65468 | 16.22371 | 1.91001 |
| 1pm | 1.96126 | 17.8533 | 1.62959 |
| 2pm | 1.81323 | 19.7245 | 1.8712 |
| 3pm | 1.26769 | 20.5548 | 0.8303 |
| 4pm | 1.1608 | 23.2677 | 2.7129 |
| 5pm | 3.21098 | 25.4005 | 2.1328 |
| 6pm | 1.79871 | 27.739 | 2.3385 |
| 7pm | 1.97995 | 29.9522 | 2.2132 |

| | | | |
|---|---|---|---|
| 8pm | 1.20924 | 31.6519 | 1.6997 |
| 9pm | 1.12313 | 33.1393 | 1.4874 |
| 10pm | 0.945368 | 34.7606 | 1.6213 |
| 11pm | 2.1985 | 36.2379 | 1.4773 |
| 12 midnight | 1.1757 | 37.7679 | 1.53 |
| 1am | 1.3693 | 0 | 0 |
| 2am | 1.07135 | 1.25669 | 1.25669 |
| 3am | 0.977846 | 2.3713 | 1.11461 |
| 4am | 0.708982 | 3.19918 | 0.82788 |
| 5am | 0.65148 | 3.68142 | 0.48224 |
| 6am | 0.684834 | 4.48966 | 0.80824 |
| 7am | 1.45638 | 5.69029 | 1.20063 |
| 8am | 2.27772 | 7.40865 | 1.71836 |
| 9am | 1.26406 | 9.23311 | 1.82446 |
| 10am | 2.47992 | 11.428 | 2.19489 |
| 11am | 2.46227 | 13.3676 | 1.9396 |
| 12pm | 2.04613 | 14.9043 | 1.5367 |
| 1pm | 0.950553 | 16.2741 | 1.3698 |
| 2pm | 1.33211 | 17.7473 | 1.4732 |
| 3.20pm | 1.1831 | 19.7906 | 2.0433 |
| 4.20 | 1.31882 | 21.3445 | 1.5539 |
| 5.20 | 1.24293 | 22.6036 | 1.2591 |
| 6.20 | 0.443227 | 23.5618 | 0.9582 |
| 7.20 | 0.500524 | 24.8362 | 1.2744 |
| 8.20 | 1.79719 | 25.6647 | 0.8285 |
| 9.20 | 0.997621 | 26.882 | 1.2173 |
| 10.20 | 1.38936 | 28.1547 | 1.2727 |
| 11.20 | 1.48051 | 29.6586 | 1.5039 |
| 12.20am | 0.976502 | 30.7692 | 1.1106 |
| 1.20 | 1.33893 | 0.456334 | 0.456334 |
| 2.20 | 1.52261 | 1.74782 | 1.291486 |
| 3.20 | 0.766791 | 2.71509 | 0.96727 |
| 4.20 | 0.934 | 3.4153 | 0.70021 |
| 5.20 | 1.1632 | 4.24192 | 0.82662 |
| 6.20 | 0.635537 | 5.11163 | 0.86971 |
| 7.20 | 1.44237 | 6.22271 | 1.11108 |
| 8.20 | 1.95762 | 7.72756 | 1.50485 |
| 9.20 | 2.06039 | 9.78108 | 2.05352 |
| 10.20 | 2.14259 | 11.6225 | 1.84142 |
| 11.20 | 1.54596 | 13.6062 | 1.9837 |
| 12.20pm | 1.76674 | 15.5503 | 1.9441 |

| | | | |
|---|---|---|---|
| 1.20 | 1.08184 | 16.9537 | 1.4034 |
| 2.20pm | 1.9384 | 18.3832 | 1.4295 |
| 3.20pm | 1.11938 | 19.6584 | 1.2752 |
| 4.20 | 1.67719 | 21.2095 | 1.5511 |
| 5.20 | 1.10864 | 22.8713 | 1.6618 |
| 6.20 | 2.07275 | 24.3349 | 1.4636 |
| 7.20 | 0.934528 | 26.0304 | 1.6955 |
| 8.20 | 0.908587 | 27.1653 | 1.1349 |
| 9.20 | 1.33109 | 28.6055 | 1.4402 |
| 10.20 | 1.43947 | 30.145 | 1.5395 |
| 11.20 | 2.05846 | 31.8277 | 1.6827 |
| 12.20 am | 1.81749 | 33.7638 | 1.9361 |
| 1.20 | 1.26199 | 0.505667 | 0.505667 |
| 2.20 | 1.21489 | 1.89817 | 1.392503 |
| 3.20 | 0.99929 | 2.94931 | 1.05114 |
| 4.20 | 0.71076 | 3.7017 | 0.75239 |
| 5.20 | 1.01509 | 4.51638 | 0.81468 |
| 6.20 | 1.10268 | 5.63799 | 1.12161 |
| 7.20 | 1.12828 | 6.81096 | 1.17297 |
| 8.20 | 1.57452 | 8.47616 | 1.6652 |
| 9.20 | 1.77574 | 10.2695 | 1.79334 |
| 10.20 | 1.50172 | 12.2005 | 1.931 |
| 11.20 | 1.89393 | 14.1877 | 1.9872 |
| 12.20pm | 1.65029 | 15.8672 | 1.6795 |
| 1.20 | 1.11861 | 17.5125 | 1.6453 |
| 2.20pm | 1.0734 | 18.9992 | 1.4867 |
| 3.20pm | 1.31257 | 20.3611 | 1.3619 |
| 4.20 | 1.82228 | 21.8148 | 1.4537 |
| 5.20 | 1.79252 | 23.8895 | 2.0747 |
| 6.20 | 1.51034 | 25.4323 | 1.5428 |
| 7.20 | 1.17172 | 26.9255 | 1.4932 |
| 8.20 | 1.76991 | 28.2556 | 1.3301 |
| 9.20 | 0.833367 | 29.4011 | 1.1455 |
| 10.20 | 1.46513 | 31.0912 | 1.6901 |
| 11.20 | 1.10665 | 32.528 | 1.4368 |
| 12.20 am | 1.21426 | 34.0011 | 1.4731 |
| 1.20 | 1.58705 | 0.483084 | 0.483084 |
| 2.20 | 1.07467 | 1.67476 | 1.191676 |
| 3.20 | 1.19853 | 2.8018 | 1.12704 |
| 4.20 | 0.637301 | 3.48513 | 0.68333 |
| 5.20 | 0.848406 | 4.27731 | 0.79218 |

| | | | |
|---|---|---|---|
| 6.20 | 1.03276 | 5.18927 | 0.91196 |
| 7.20 | 1.43762 | 6.57754 | 1.38827 |
| 8.20 | 1.16444 | 8.86909 | 2.29155 |
| 9.20 | 1.27024 | 10.7667 | 1.89761 |
| 10.20 | 1.8795 | 12.7325 | 1.9658 |
| 11.20 | 1.49869 | 14.4113 | 1.6788 |
| 12.20pm | 1.20253 | 16.3075 | 1.8962 |
| 1.20 | 1.99102 | 17.9025 | 1.595 |
| 2.20pm | 2.17469 | 19.4583 | 1.5558 |

**A9: Bill of quantities for the integrated solar and steam system**

*Table A9-1- Bill of quantities for the integrated solar and steam system for Hospital No.1 (AK)*

| **Item No.** | **Description** | **Unit** | **Quantity** | **Rate (Kshs)** | **Amount (Kshs)** |
|---|---|---|---|---|---|
| 1.01 | Provide bond as stated in the published conditions of subcontract | Item | 1 | | 50,000.00 |
| 1.02 | Provide insurance as required in the subcontract conditions | Item | 1 | | 30,000.00 |
| 1.03 | Fabrication of store, workshop, lock-up etc as necessary | Item | 1 | | 20,000.00 |
| 1.04 | Preparation of "As installed" record drawings | Item | 1 | | 10,000.00 |
| 1.05 | Printing of copies of item 1.04 above. | Item | 1 | | 5,000.00 |
| **M1** | **Total Carried Forward To Collection Page** | | | | **115,000** |

| Item No. | Description | Unit | Quantity | Rate (Kshs) | Amount (Kshs) |
|---|---|---|---|---|---|
| | **Solar Water Heaters:** | | | | |
| | Supply install and commission solar water heaters as per the details below: The contractor to allow for all accessories to ensure an operational system to the satisfaction of the Engineer. | | | | |
| | The installation of the solar water heating system shall be in accordance with the code of practice –solar water heating for domestic hot water: Kenya standard KS 1860: 2008 | | | | |
| 2.00 | **Flat plate Solar water heaters:** | | | | - |
| 2.01 | Solar water heaters as "DAYLIFF Model UFS 200D - UltraSun premium" with collector area -2.4m² | No | 60 | 80,000 | 4,800,000 |
| 2.02 | **Accessories:** | | | | |
| 2.03 | Temperature and pressure relief valve for solar systems to EN 1490: 7-10 BAR. Set temperature: 90°C, Pressure setting: 6,7 and 10 bar | NO | 4 | 4,000 | 16,000 |
| 2.04 | Chrome plated automatic air vent for solar thermal systems. Maximum working pressure: 10 bar, maximum discharge pressure: 5 bar, temperature range -30 to 200°C | NO | 4 | 4,000 | 16,000 |
| 2.05 | 25mm diameter chrome plated shut -off cock complete with seal as " CLIMACENTO" or equal ; maximum working pressure: 10 bar and temperature range -30 to 200°C | No | 60 | 4,000 | 240,000 |
| 2.06 | 970 litre capacity stainless steel Hot water storage tanks as "SOLITANK 1000 code Ma 0493" each complete with a coil heat exchanger for glycol/ hot water | No | 2 | 300,000 | 600,000 |
| 2.07 | Glycol/ hot water mixture - circulation pump as Grundfos model UPS 100 rated at 2m³/h at 0.6 bar | No | 2 | 150,000 | 300,000 |
| **M2** | **Total Carried Forward To Collection Page** | | | | **5,972,000** |

| Item No. | Description | Unit | Quantity | Rate (Kshs) | Amount (Kshs) |
|---|---|---|---|---|---|
| 3.01 | **Piping:** | | | | |
| 3.02 | Supply , install and commission CAGTHERM PPRC Piping to PN 20 | | | | |
| 3.03 | DIN 8077-78 PPRC 3 TM 95 complete with fittings: | | | | |
| 3.04 | **Piping:** | | | | |
| 3.05 | 50mmØ PPRC Piping. | LM | 80 | 400 | 32,000 |
| 3.06 | 32 mm Ø Ditto. | LM | 90 | 200 | 18,000 |
| 3.07 | 20 mm Ø Ditto. | LM | 50 | 100 | 5,000 |
| 3.08 | **Fittings:** | | | | - |
| 3.09 | **90 Degree Bends:** | | | | - |
| 3.10 | 50 mm Ø PPRC 90 Degree Bends: | No. | 30 | 110 | 3,300 |
| 3.11 | 32 mm Ø Ditto. | No. | 60 | 75 | 4,500 |
| 3.12 | 20 mm Ø Ditto. | No. | 100 | 50 | 5,000 |
| 3.13 | **Tees:** | | | | - |
| 3.14 | 50 X 50 x 32 mm Ø PPRC tees | No. | 8 | 120 | 960 |
| 3.15 | 32X 32 x 20 mm Ø PPRC tees | No. | 40 | 120 | 4,800 |
| 3.16 | **Sockets /Unions:** | | | | - |
| 3.17 | 50 mm Ø PPRC Sockets / Unions | No. | 8 | 150 | 1,200 |
| 3.18 | 32 mm Ø Ditto | No. | 130 | 32 | 4,160 |
| 3.19 | **Reducers:** | | | | - |
| 3.20 | 50 x 32 mm Ø PPRC Reducers | No. | 50 | 100 | 5,000 |
| 3.21 | 32 x 20 mm Ø Ditto | No. | 50 | 75 | 3,750 |
| 3.22 | **Pipe Clips:** | | | | - |
| 3.23 | 50 mm Ø Pipe Clips | No. | 25 | 27 | 675 |
| 3.24 | 40 mm Ø Ditto | No. | 10 | 21 | 210 |
| 3.25 | 32 mm Ø Ditto | No. | 25 | 12 | 300 |
| 3.26 | **End Caps:** | | | | - |
| 3.27 | 50 mm Ø End caps | No. | 5 | 50 | 250 |
| 3.28 | 32 mm Ø Ditto | No. | 5 | 40 | 200 |
| 3.29 | 20 mm Ø Ditto | No. | 5 | 30 | 150 |
| 3.29 | **Male Screwed Adapter:** | | | | - |
| 3.30 | 32 mm Ø Ditto | No. | 50 | 109 | 5,450 |
| 3.30 | 20 mm Ø Ditto | No. | 25 | 82 | 2,050 |

| | | | | | |
|---|---|---|---|---|---|
| 3.31 | **Female Screwed Adapter:** | | | | - |
| 3.31 | 32 mm Ø Ditto | No. | 30 | 350 | 10,500 |
| 3.32 | 20 mm Ø Ditto | No. | 20 | 293 | 5,860 |
| **M3** | **Total Carried Forward To Collection Page** | | | | **113,315** |

| | **Collection Page** | | | | |
|---|---|---|---|---|---|
| **Item No.** | **Description** | **Unit** | **Quantity** | **Rate (Kshs)** | **Amount (Kshs)** |
| **M2** | Solar water heaters | Item | 1 | | 5,972,000 |
| **M3** | pipework and fittings | Item | 1 | | 113,315 |
| | **Total Price Carried To Summary Page** | | | | **6,085,315** |
| | **Summary Page** | | | | |
| **Item No.** | **Description** | **Unit** | **Quantity** | **Rate (Kshs)** | **Amount (Kshs)** |
| | Preliminaries and general conditions | Item | | | 115,000 |
| | Total for supply, installation and commissioning of the works. | Item | | | 6,085,315 |
| | **Total Price Carried To Form Of Tender** | | | | **6,200,315** |